# Passaic Valley Sewerage Commissioners

# CSO Characterization Study – Modeling Report

Submitted on behalf of the
Towns of Harrison and Kearny,
Borough of East Newark, and the City of Paterson
NJPDES Permit No. NJ0105023

**December 2003**

as prepared by HydroQual

Hatch Mott MacDonald
Millburn, New Jersey

# FINAL REPORT

# PASSAIC VALLEY SEWERAGE COMMISSIONERS CSO DISCHARGE CHARACTERIZATION STUDY COMBINED SEWER SYSTEM MODELING

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HydroQual

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Environmental
Engineers & Scientists

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| BOD | Biochemical Oxygen demand |
| CAMCE | Charles A. Manganaro Consulting Engineers |
| COD | Chemical Oxygen Demand |
| CSO | Combined Sewer Overflow |
| EPA | United States Environmental Protection Agency |
| EWR | Newark International Airport |
| FC | Fecal Coliform |
| FT | feet |
| HMM | Hatch Mott MacDonald, formerly known as Killam Associates |
| IN | Inches |
| JCSA | Jersey City Sewerage Authority |
| MGD | Million gallons per day |
| MLE | Maximum Liklihood Estimator |
| NCDC | National Climatic Data Center |
| NJDEP | New Jersey Department of Environmental Protection |
| NJPDES | New Jersey Pollution Discharge Elimination System |
| NOAA | National Oceanic and Atmospheric Administration |
| $NH_3$ | Ammonia Nitrogen |
| $NO_2$ | Nitrite Nitrogen |
| $NO_3$ | Nitrate Nitrogen |
| OP | Orthophosphorus |
| PS | Pump Station |
| PVSC | Passaic Valley Sewerage Commissioners |
| PVWC | Passaic Valley Water Commission |
| SS | Suspended Solids |
| SWMM | Storm Water Management Model |
| TDS | Total Dissolved Solids |
| TH | Total Hardness |
| TKN | Total Kjeldahl Nitrogen |
| TP | Total Phosphorus |
| TSS | Total Suspended Solids |
| WPCF | Water Pollution Control Facility |

# EXECUTIVE SUMMARY

The PVSC operates a Water Pollution Control Facility (WPCF) located in Newark, New Jersey. This WPCF is the fifth largest facility of its kind in the United States and services the wastewater needs of residential, commercial and industrial users located within 48 communities in Essex, Hudson, Bergen and Passaic counties with a total population of about 1.3 million people.

The PVSC has undertaken a Combined Sewer Overflow (CSO) Characterization Study pursuant to permitting requirements of its New Jersey Discharge Elimination System (NJPDES) permit No. NJ0105023, Part V.B., Condition 4a, 4d, 4e, and 4f. The service area includes combined and separately sewered systems and PVSC has undertaken to perform this study for all member municipalities with combined sewer systems except the City of Newark, which elected to complete their own work. The PVSC has conducted monitoring and modeling of the PVSC Interceptor Sewer System pursuant to the NJPDES Permit through a grant from the Act. A computer model of the PVSC interceptor sewer system and tributary collection systems has been constructed, calibrated, and verified in this study. The model is based on the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM). The purpose of constructing the model is to develop a tool suitable for evaluating current sewer system flow and solids transport capacity and design alternatives while also enabling PVSC to estimate CSO pollutant loadings from the PVSC service area to the Passaic River and its tributaries.

The PVSC WPCF provides wastewater treatment for an extensive and complicated sewer system. The system has a large service area with miles of interceptor sewers, numerous regulators and pump stations, among other features. The PVSC service area is approximately 150 square miles extending from Newark Bay to the upper regions of the Passaic River Basin adjacent to Great Falls in Paterson. The PVSC Interceptor Sewer System is characterized by combined and separately sewered drainage areas that are conveyed via local collection systems in the municipalities to the PVSC interceptor sewer. In municipalities with combined sewer systems, wastewater flows from the collection system pass through PVSC regulators, which control flow to interceptor sewers. The collection systems are owned and operated by the municipalities while regulator chambers, interceptor sewers, and the WPCF are owned and operated by PVSC. The model includes all regulators and the tributary drainage areas to individual regulators represented as draining to one pipe upstream of these regulators. All the outfalls and internal overflow reliefs in the Cities of Paterson and Newark are included. The influence of high tide leve s that alter overflow patterns from individual outfalls was characterized by specifying tide gates and tide water levels at each outfall, and the automatic/manually operated gates in the system were included so that the duration and peaking characteristics of overflows could be represented well.

The PVSC interceptor sewer model was calibrated and verified using precipitation and hydraulic data collected under various sampling programs. The model calibration and verification applies to general reaches of the interceptor sewer system, and some of the individual regulators where monitoring data were available. Model calibration and verification then proceeded by selecting periods from program monitoring efforts using selection rationales that would be most appropriate for the eventual use of the model. Calibration and verification of the interceptor sewer system was then completed for several dry and wet weather simulation periods.

Runoff parameters such as drainage area, land slope, width of overland flow, Manning's surface roughness coefficients, land infiltration, evaporation, depression storage, and percent imperviousness were calibrated for generating precipitation induced runoff. Using the Transport and Extran blocks of SWMM, the dry weather flow at individual regulator drainage areas were input into the model to simulate flow and water levels at the metering locations. Visual comparison of observed and modeled flows and water levels was made to assess the accuracy of predictions and to adjust appropriate hydraulic model parameters such as gate operations, head losses and pump rating curves to obtain favorable comparison between modeled and monitored data.

The overflow quantity and quality data observed in the Towns of Kearny and Harrison and in the City of Paterson were reviewed to characterize the concentrations of fifteen water quality parameters including BOD, nutrients, solids and coliform bacteria. Event mean concentrations and site mean concentrations were developed for each of the eight outfalls that represent different landuse patterns. The concentration data was then applied on a system-wide basis based on geographical vicinity and similarity in landuses between monitored drainage areas and the remaining drainage areas within the study area. These concentration data along with overflow volume data generated by the SWMM model can be used in the future for developing pollutant loads discharged from the PVSC service area into the Passaic River and its tributaries.

The calibrated hydraulic model can also be used to evaluate and select engineering alternatives that, for example, can minimize CSO discharges and maximize treatment.

Section 1

# SECTION 1

# INTRODUCTION

The Passaic Valley Sewerage Commissioners (PVSC) was formed in 1902 by a special act of the New Jersey State Legislature to reduce pollution of the Passaic River and its tributaries. The organization is one of the oldest and largest regional sewerage agencies in the United States and is directed by a Board of Commissioners appointed by the State of New Jersey's Governor. The PVSC operates a Water Pollution Control Facility (WPCF) located in Newark, New Jersey. The WPCF is the fifth largest facility of its kind in the U.S. and services the wastewater needs of residential, commercial and industrial users located within 48 communities in Essex, Hudson, Bergen and Passaic counties with a total population of about 1.3 million people.

The PVSC has undertaken a Combined Sewer Overflow Characterization Study pursuant to permitting requirements of its New Jersey Pollution Discharge Elimination System (NJPDES) permit No. NJ0105023, Part V.B., Condition 4a, 4d, 4e, and 4f. The PVSC service area includes combined and separately sewered systems and has undertaken the work effort described herein for all member municipalities with combined sewer systems except the City of Newark, which elected to complete their own work. The New Jersey Sewage Infrastructure Improvement Act establishes comprehensive requirements for the state and municipalities/authorities to address combined sewer overflows (CSO) and stormwater management. The New Jersey Department of Environmental Protection (NJDEP) provides grants for planning and design components of CSO control projects to eliminate dry weather overflows and to control solids and floatables discharges from combined sewers. The PVSC has undertaken monitoring and modeling of the Interceptor Sewer System pursuant to the NJPDES Permit through a grant from the Act. A computer model of the PVSC Interceptor Sewer System and tributary collection systems has been constructed, calibrated, and verified. The model is based on the U.S. Environmental Protection Agency (EPA) Storm Water Management Model (SWMM). The purpose of constructing the model is to develop a tool suitable for evaluating current sewer system flow and solids transport capacity and design alternatives while also enabling PVSC to estimate CSO pollutant loadings from the PVSC service area to the Passaic River and its tributaries. Quantification and qualification of these loadings may subsequently be used in water quality improvement projects for the Passaic River and its tributaries.

The following sections of this report provide information on the development of a computer model of the PVSC Interceptor Sewer System. Section 2 describes the project area represented by the model. Section 3 describes precipitation and hydraulic data collection efforts, reviews the data, and

discusses its application to the model. A description of the model and its various components are described in Section 4, which is followed by descriptions of model calibration and verification in Section 5. Section 6 discusses the characterization of CSOs from outfalls that represent different landuse patterns developed from the outfall monitoring performed by Hatch Mott MacDonald (formerly Killam Associates)[7] in the Towns of Kearny and Harrison and the City of Paterson. An approach for estimating pollutant loads from drainage areas that were not monitored within the study area is also discussed in Section 6.

Section 2

# SECTION 2

# PROJECT AREA CHARACTERISTICS

The PVSC WPCF provides wastewater treatment for an extensive and complicated sewer system. The system has a large service area with miles of interceptor sewers, numerous regulators and pump stations, among other features. The following describes the service area, the interceptor sewer system, and general climatic characteristics of the project area.

## 2.1 SERVICE AREA

The PVSC provides wastewater treatment to 48 municipalities within their northeast New Jersey service area. The service area is approximately 150 square miles extending from Newark Bay to the upper regions of the Passaic River Basin adjacent to Great Falls in the City of Paterson. Flow is conveyed to the PVSC WPCF through an interceptor sewer system and force mains. The PVSC Interceptor Sewer System is characterized by combined and separately sewered drainage areas that are conveyed via local collection systems in the municipalities to the PVSC interceptor sewer. In municipalities with combined sewer systems, wastewater flows from the collection system pass through PVSC regulators, which control flow to the interceptor sewers. The collection systems are owned and operated by individual municipalities while the regulator chambers, interceptor sewers, and the WPCF are owned and operated by PVSC.

Municipalities with combined sewer systems include the Towns of Harrison and Kearny, the Borough of East Newark, and the Cities of Newark, Paterson, Jersey City, and Bayonne. The Cities of Bayonne and Jersey City own and operate their own combined sewer systems. The Jersey City Sewerage Authority and City of Bayonne (JCSA/Bayonne) Joint Force Main conveys flow from Jersey City, Bayonne, and South Kearny to the PVSC WPCF just upstream of the primary clarifiers. Accordingly, these municipalities do not enter the PVSC transport system (interceptor sewers) and are not included in the project area. Combined sewers in the project area service approximately 13,300 acres while separate sewers service approximately 56,780 acres.[1] The project area of this analysis includes all service areas that are directly connected to the PVSC Interceptor Sewer System.

## 2.2 INTERCEPTOR SEWER SYSTEM

The PVSC Interceptor Sewer Systems consists of two distinct interceptor sewer systems that meet at the headworks of the WPCF: the Main Interceptor Sewer and the South Side Interceptor Sewer.

The Main Interceptor Sewer extends approximately twenty-two miles from the WPCF in the City of Newark in Essex County to the City of Paterson in Passaic County, generally following the west bank of the Passaic River (Figure 2-1). Several branch interceptor sewers connect to the Main Interceptor Sewer. The South Side Interceptor Sewer is approximately six miles long and is located entirely within the City of Newark.

The PVSC Interceptor Sewer System is constructed of monolithic concrete.[2] The hydraulic shape varies from circular to horseshoe with sewer sizes ranging from a 3.75-foot diameter circular pipe in Paterson to a 12.5-foot wide horseshoe pipe in Newark. Figure 2-2 presents typical schematics of the circular and horseshoe pipes that constitute the interceptor sewer system.

There are eleven major branch interceptor sewers (see Figure 2-1) connecting to the Main Interceptor Sewer:

1. Prospect Street Branch Sewer
2. Lawrence Street Branch Sewer
3. Warren Street Branch Sewer
4. Rutherford/Lyndhurst Branch Intercepting Sewer
5. Garfield/Wallington/Passaic Branch Intercepting Sewer
6. Rutherford/East Rutherford Branch Intercepting Sewer
7. Kearny/North Arlington Branch Intercepting Sewer
8. Kearny/East Newark/Harrison Branch Intercepting Sewer
9. Kearny/Harrison/Newark Branch Intercepting Sewer
10. Brown Street Branch Intercepting Sewer
11. Newark (Jabez Street) Branch Sewer

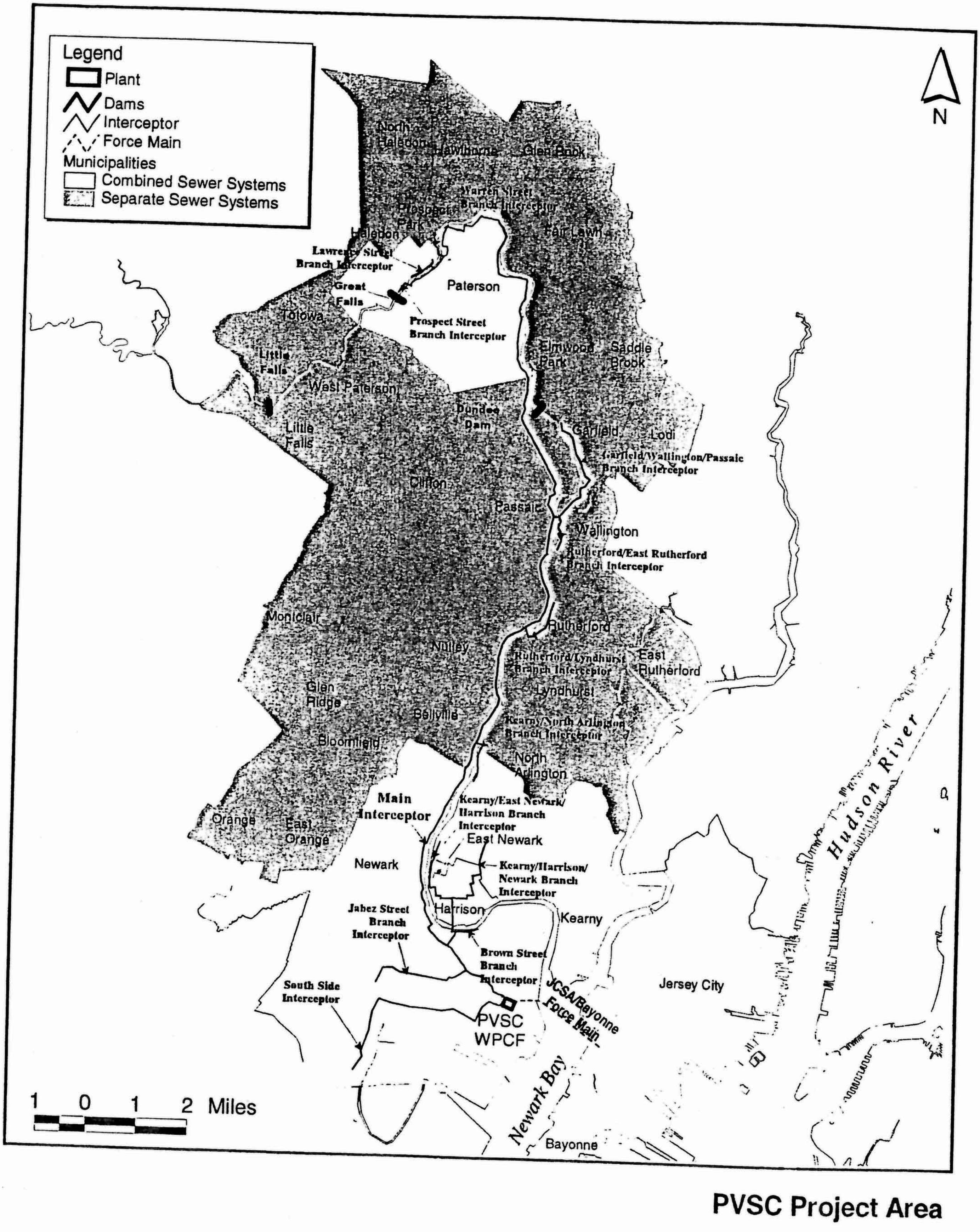
The interceptor sewer system includes pump stations (PS) at Passaic (Wallington PS) and Clifton (Yantacaw PS) and a Main pump station at the PVSC WPCF. The system also features three Venturi meters, five river crossings, three internal relief systems, and 59 regulators, ten of which are remotely operated by PVSC WPCF personnel. Figure 2-3 provides the locations of flow regulators on the PVSC Interceptor Sewer System.

## 2.3 CLIMATE

Geographically located within the middle latitudes about halfway between the Equator and the North Pole, and bordered on the east by the Atlantic Ocean, New Jersey is influenced by wet, dry, hot, and cold airstreams, resulting in daily weather that is highly variable.[3] The project area is in the New

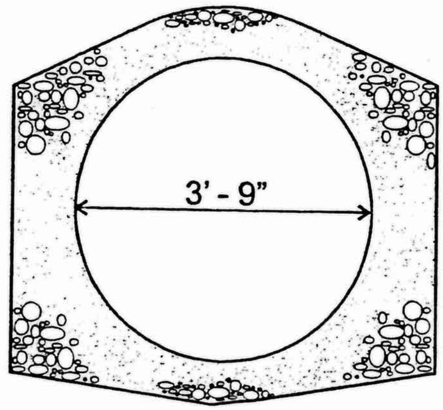
Jersey Central Climate Zone, as shown in Figure 2-4. The northern edge of the zone often delineates where freezing and non-freezing precipitation occurs during the wintertime. The Central Zone is known to contain 'heat islands' where, because of the concentration of buildings and paved surfaces, observed nighttime temperatures are regularly warmer than those in surrounding suburban areas. The average number of freeze-free days in the central zone is 179 compared to 217 along the seacoast.

Historical precipitation data is available at the Newark International Airport (EWR), located in the southern portion of the project area. The average annual precipitation at EWR is approximately 43 inches. Most areas of New Jersey experience approximately 25 to 30 thunderstorms per year, with fewer storms occurring near the coast than farther inland. Measurable precipitation is recorded approximately 120 days during the year. Autumn months are usually the driest with an average of eight days per month with measurable precipitation. As shown in Figure 2-5, the average monthly precipitation recorded at EWR varies from 2.98 inches per month in February and October to a high of 4.23 inches in July. The shaded bars indicate monthly precipitation during the 1997-2001 period in which project activities occurred.



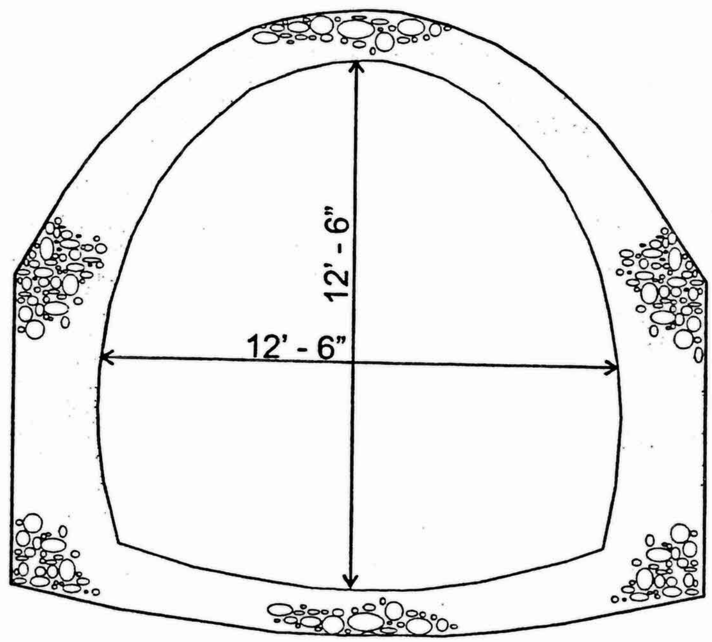

**PVSC Project Area**

## 1) Typical Main Interceptor - Circular



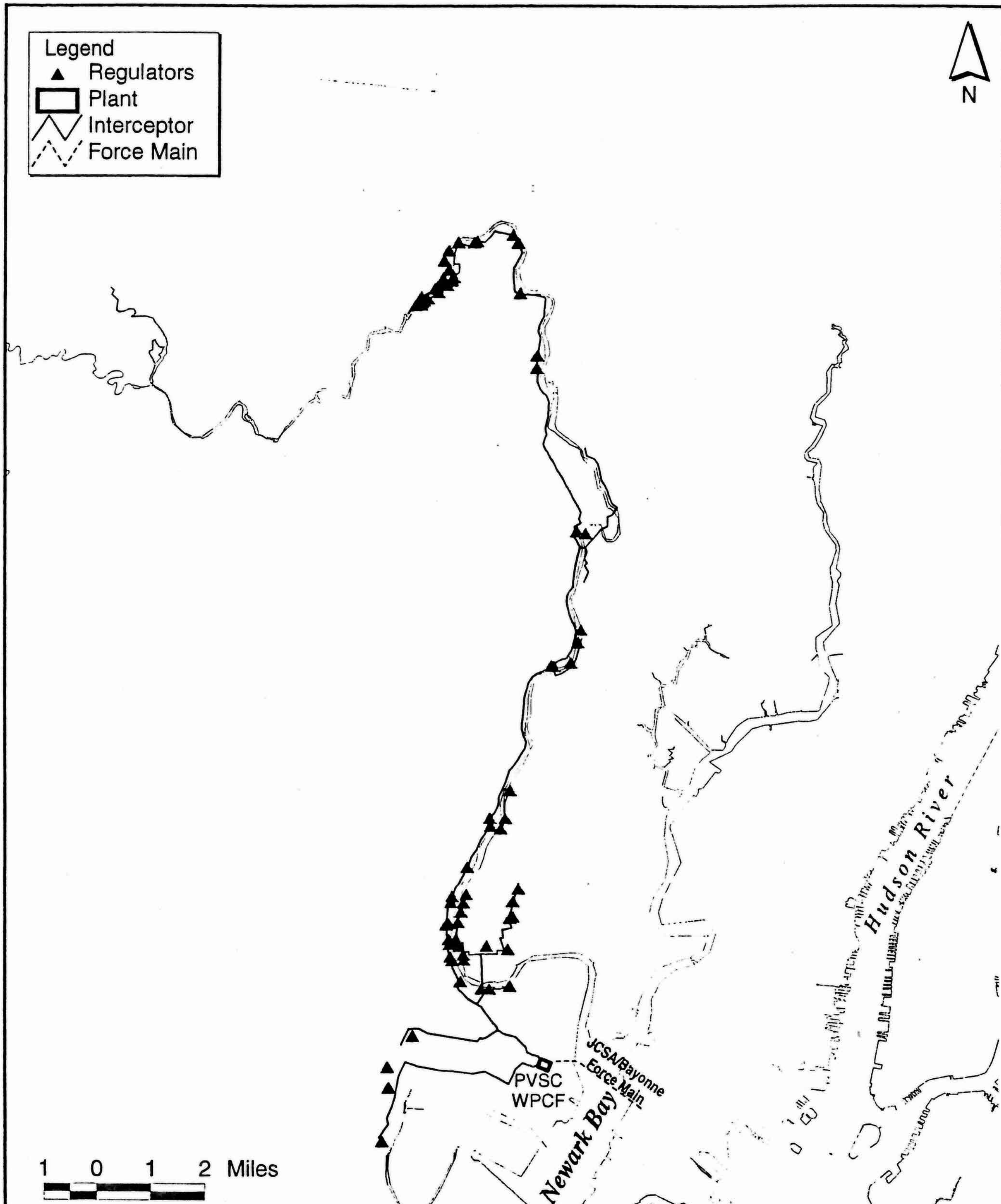

**3' - 9" Sewer**

## 2) Typical Main Interceptor - Horseshoe




**12' - 6" Sewer**

Typical PVSC Circular and Horseshoe Pipes.




## PVSC Flow Regulators

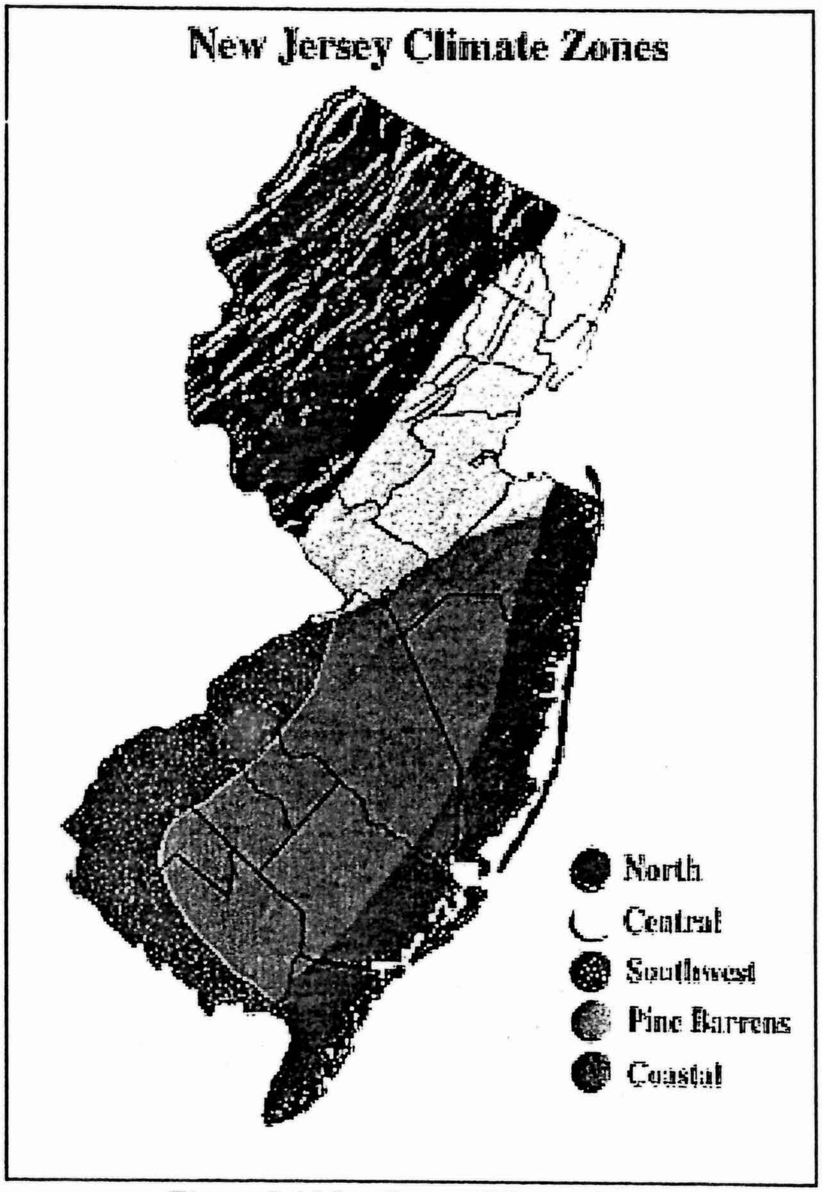



Figure 2-4 New Jersey Climate Zones

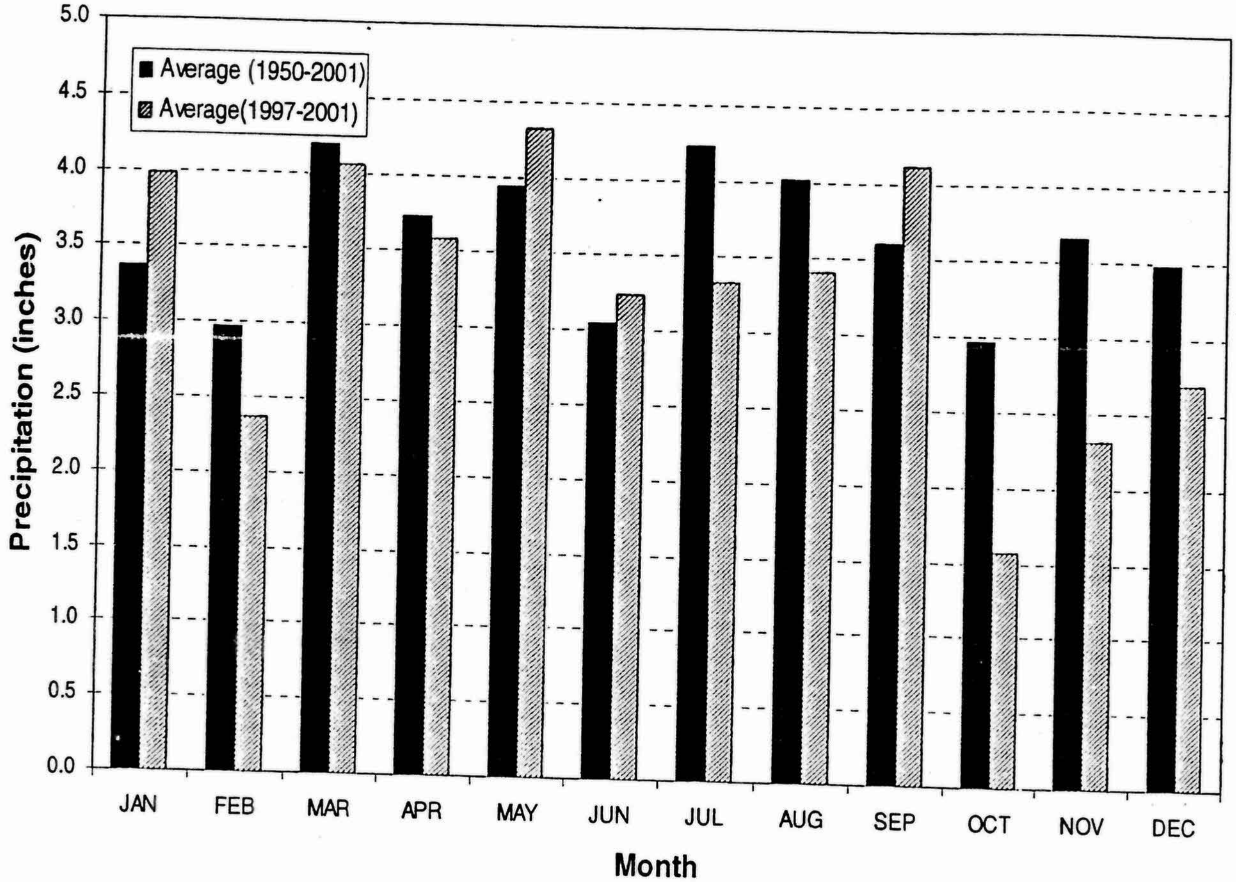



Figure 2-5. Precipitation Data Comparison to Historical Record

# Section 3

# SECTION 3

# DATA COLLECTION AND ANALYSIS

A field-monitoring program for the PVSC Interceptor Sewer System and surrounding project area was conducted to gather precipitation and hydraulic data during 1997-1998 period. Each of these data components was collected to construct, calibrate, and verify the model of the interceptor sewer system. Permanent and temporary recording devices located throughout the project area were used in this effort. In addition, the flow and water quality data collected during 1999-2001 period at outfalls in Paterson, East Newark, Kearny, and Harrison were used to characterize CSOs. The overflow data was used in the hydraulic model calibration/verification and the water quality data was used to generate pollutant concentrations. The following describes the data sources and their application to PVSC interceptor sewer modeling.

## 3.1 PRECIPITATION DATA COLLECTION

Apart from sanitary sewer flow calculations, hydrology is the main driving force of a sewer system model in which wet weather flow enters the system. Precipitation data is therefore necessary for calibrating and verifying the integrity of such a sewer system model. Precipitation data is recorded at two existing locations in the southern portion of the project area: EWR and the PVSC WPCF. Precipitation data recorded at EWR was obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). Data from the two existing precipitation-monitoring devices are recorded in different time intervals. The EWR data is published by NCDC in a 60-minute interval. Precipitation monitoring at the PVSC WPCF yields data on a 2.5-minute interval, but the September 1997 to February 1998 period contains many missing records. Therefore, data from this gage were not used for calibration of the model. Since the interceptor sewer system is over 20 miles in length and services over 150 square miles, variations in rainfall may be expected over the entire interceptor sewer system. Therefore, additional precipitation monitoring was required throughout the project area.

Hatch Mott MacDonald (formerly Killam Associates) installed six temporary precipitation-monitoring devices throughout the project area, which was detailed in separate work plans.[4,5] Devices were installed in the Towns of Kearny (Police Department), Harrison (Fire Department Headquarters), and Bloomfield (Fire Department Headquarters) to provide additional precipitation data for the southern portion of the Interceptor Sewer System. A device was installed in

the City of Passaic (PVSC Wallington Sewage Pumping Station) to provide data for the central portion of the system. Two devices were installed in the City of Paterson (Madison Fire Station and Stanley Levine Reservoir) to provide data for the northern portion of the system. The data was recorded and processed in a 10-minute interval for the period from January 1997 through December 2001. Figure 3-1 presents the locations of these devices as well as the existing data sources of EWR and the PVSC WPCF. Table 3-1 provides rainfall statistics for storm volumes, intensities, and durations for the period of record used in the analysis. Precipitation recording at the PVSC WPCF was halted during this period and statistics for this location are not presented in Table 3-1.

**Table 3-1. Summary of Precipitation Data Collection (January 1997-December 1998)**

| Monitoring Location | Average Storms per Month | Storm Volume (inches) | | Storm Intensity (inches/hour) | | Storm Duration (hours) | |
|---|---|---|---|---|---|---|---|
| | | Average | Max | Average | Max | Average | Max |
| Stanley Levine Reservoir, Paterson | 8.9 | 0.34 | 3.19 | 0.05 | 0.39 | 6.31 | 54.00 |
| Madison Fire Station, Paterson | 9.0 | 0.35 | 3.11 | 0.05 | 0.39 | 6.11 | 54.00 |
| PVSC Wallington PS, Passaic | 9.9 | 0.32 | 5.34 | 0.04 | 0.26 | 6.15 | 73.00 |
| Bloomfield Fire Dept. | 9.2 | 0.41 | 6.75 | 0.06 | 0.57 | 6.40 | 58.00 |
| Kearny Police Department | 9.5 | 0.35 | 5.99 | 0.05 | 0.34 | 5.81 | 57.00 |
| Harrison Fire Dept.* | 8.9 | 0.35 | 2.50 | 0.05 | 0.46 | 6.47 | 58.00 |
| Newark Internat'l Airport (EWR) | 9.7 | 0.36 | 4.95 | 0.05 | 0.43 | 6.16 | 59.00 |

*Note: Harrison data collection began in October 1997.

An analysis of the rainfall data was conducted to determine the return period or frequency of specific storm events, which may be monitored during the course of CSO studies. Another objective of the analysis was to determine similarities or differences in rainfalls within the PVSC service area. This analysis was presented in a separate report.[6] Long-term rainfall characterizations and statistical analyses were performed on data from EWR and a historical station in the Town of Little Falls. Data for Little Falls was obtained from NCDC. Intensity-Duration-Frequency curves were developed and presented in the report for EWR. Comparisons between EWR and Little Falls were conducted to determine if consistent spatial differences in rainfall patterns could be identified within the project area. This analysis concluded that "the northern end of the project area (near Paterson) experiences larger storm events with somewhat shorter durations and hence higher average intensities." The report also provided hourly data collected at the temporary precipitation-monitoring devices for the period of January 1997 through December 1998.

The precipitation data was used for a variety of purposes besides driving the interceptor sewer system model during simulations. For instance, the data was analyzed to identify wet and dry periods. Dry periods were further analyzed for determining model parameters such as average daily sanitary flows and diurnal characteristics. Once the dry and wet weather periods were identified, specific periods were selected for model calibration and verification. Applications of the data are further described in later sections.

## 3.2 HYDRAULIC DATA COLLECTION

While precipitation data provides information on the amounts of rainfall, which generates runoff entering the PVSC Interceptor Sewer System, hydraulic data is required to observe the response of the system to such events. This is best accomplished by monitoring flow and hydraulic elevations at various locations within the system. PVSC owns and operates permanent flow and hydraulic elevation monitoring devices both in the interceptor sewer system and at the PVSC WPCF. This network of devices was supplemented by installing additional temporary meters throughout the interceptor sewer system and at selected outfalls. Field monitoring efforts also yielded summary hydraulic data for virtually all PVSC regulators in the system. The following describes permanent and supplemental monitoring efforts within the interceptor sewer system that provided data for this analysis. Outfall monitoring is discussed in Section 3.3. Figure 3-2 presents the locations of permanent and supplemental hydraulic meters.

### 3.2.1 Permanent Hydraulic Monitoring

Flow is regularly monitored by PVSC at numerous points in its system. Meters monitor flow entering the system from each of the separately sewered municipalities that PVSC serves as well as within the system itself. Flow is monitored at three permanent Venturi meters constructed along the Main Interceptor Sewer. These meters are located in Paterson, Passaic, and at Second River on the northern border of Newark. Flow is also monitored at the WPCF. These monitoring locations provide a profile for the amount or proportion of flow entering the interceptor sewer system at different points.

The Paterson Venturi meter measures flow from the City of Paterson combined sewer system and separately sewered towns of Totowa, West Paterson, part of Little Falls, Haledon, North Haledon, Prospect Park, Hawthorne, Glen Rock, Fair Lawn, and Elmwood Park. The Passaic Venturi meter measures cumulative flow recorded at the Paterson Venturi meter plus sanitary flow from the separately sewered municipalities of Garfield, Saddle Brook, Lodi, Wallington, East Rutherford, a portion of Rutherford, Passaic, and parts of Clifton. The Second River Venturi meter measures cumulative flow recorded at the Passaic Venturi meter plus sanitary flow from the separately sewered municipalities of

Lyndhurst, North Arlington, Nutley, Belleville, and parts of Rutherford and Clifton. This meter also monitors a portion of the flow from the combined sewer municipality of Kearny. Finally, the flow is monitored at PVSC WPCF, which includes cumulative flow recorded at the Second River Venturi meter plus flow from the combined sewer systems of Newark, East Newark, Harrison, and part of Kearny, the separately sewered municipalities of Orange, East Orange, Bloomfield, Glen Ridge, Montclair and part of Little Falls, and the JCSA/Bayonne Force Main with combined sewer flow from Jersey City, South Kearny, and Bayonne. This analysis used the period of record of September 1997 to December 1999 for this summarization of data.

**Table 3-2. Summary of Hydraulic Data Collection**

| Location | Town | Status | Data Type | Units | Data Summary | | |
|---|---|---|---|---|---|---|---|
| | | | | | mean | min | max |
| Montgomery Street | Paterson | Temporary | Level | (FT) | 3 | 2 | 9 |
| Second Avenue | Paterson | Temporary | Flow | (MGD) | 23 | 10 | 42 |
| Paterson Venturi Meter | Paterson | Permanent | Flow | (MGD) | 46 | 21 | 100 |
| Hamilton Avenue | Clifton | Permanent | Level | (FT) | 4 | 1 | 21 |
| Hope and Jefferson | Paterson | Temporary | Flow | (MGD) | 54 | 29 | 100 |
| Passaic Venturi Meter | Passaic | Permanent | Flow | (MGD) | 101 | 28 | 148 |
| Passaic Level | Clifton | Temporary | Level | (FT) | 4 | 2 | 6 |
| Second River Venturi Meter | Newark | Permanent | Flow | (MGD) | 113 | 30 | 187 |
| Union Outlet | Newark | Permanent | Flow | (MGD) | 20 | 7 | 46 |
| Second River | Newark | Permanent | Level | (FT) | 6 | 2 | 21 |
| Raymond Plaza | Passaic | Temporary | Flow | (MGD) | 185 | 120 | 310 |
| Van Buren | Newark | Temporary | Flow | (MGD) | 14 | 6 | 63 |
| Jabez Street | Newark | Temporary | Flow | (MGD) | 5 | 2 | 61 |
| South Side Interceptor | Newark | Temporary | Flow | (MGD) | 23 | 5 | 90 |
| WPCF Forebay | Newark | Permanent | Level | (FT) | 84 | 79 | 90 |
| JC/SKB Force Main | Newark | Permanent | Flow | (MGD) | 59 | 19 | 91 |
| PVSC WPCF | Newark | Permanent | Flow | (MGD) | 279 | 125 | 573 |

Note: Locations of the meters described above are shown in Figure 3-2.

PVSC also owns and operates a number of permanent meters to continuously monitor flow entering the PVSC Interceptor Sewer System from separately sewered municipalities and industries for

billing purposes. This data is recorded on circular charts and processed by PVSC to develop weekly average flow data. The period of record of September 1992 through October 1995 plus September and October 1997 was used in this analysis. This data, along with that provided by permanent Venturi meters on the Main Interceptor Sewer, were used to proportionally identify flow entering the interceptor sewer system from the municipalities and industries.

Permanent hydraulic elevation monitoring is conducted at only two locations within the interceptor sewer system. These locations are the Main Interceptor Sewer at Hamilton Avenue in Clifton and the Second River Venturi meter. Hydraulic elevation is also measured in the Forebay of the PVSC WPCF headworks. This analysis used the elevation data periodically monitored during the period from September 1997 to December 2001.

### 3.2.2 Supplemental Hydraulic Monitoring

Hatch Mott MacDonald (formerly Killam Associates) installed temporary meters throughout the interceptor sewer system and at selected regulators to provide flow and hydraulic elevation data to supplement those provided by the permanent meters of PVSC. A separate work plan describes the locations and devices used for this effort.[4] The locations of temporary meters were selected to provide detailed information at significant points in the interceptor sewer system. These points include branch interceptor sewers and points along the Main Interceptor Sewer between the existing meters where no data is recorded for long reaches. A baseline flow-monitoring program was also conducted by Hatch Mott MacDonald to characterize flow entering the interceptor sewer system at each of the PVSC regulators.

Temporary flow meters were installed along the Main Interceptor Sewer at Second Avenue in Paterson, at Hope Avenue and Jefferson Street in Passaic, and at Raymond Plaza in Newark. A flow meter was installed on a branch interceptor sewer at Van Buren Street in Newark to monitor flow from Kearny, Harrison, East Newark, and a portion of Newark. A flow meter was installed at Jabez Street in Newark to monitor flow from another portion of Newark. Finally, a meter was installed on the South Side Interceptor Sewer to monitor flow from the remainder of Newark. The meters at Jabez Street, Raymond Plaza, Van Buren Street, and on the South Side Interceptor Sewer provide a fairly comprehensive accounting of flow entering the PVSC system from the City of Newark. The meters recorded data with a 10-minute interval. The meters on the interceptor sewer system were installed in January 1997 and removed in March 1999.

Temporary hydraulic elevation meters were installed at two locations on the Main Interceptor Sewer. One meter was installed at Montgomery Street in Paterson. The second meter, Passaic Level,

was installed near the intersection of Kingsland Avenue and Yantacaw Street in Clifton. Similar to the temporary flow meters, these meters on the interceptor sewer were installed in January 1997 and removed in March 1999, and recorded data with a 10-minute interval. This analysis used the period of record of January 1997 to December 1998 for this data source.

A monitoring program was also conducted to further characterize quantity and quality of combined sewerage entering the PVSC Interceptor Sewer System. The objectives of the monitoring program included development of dry and wet weather quantity and quality data to be used in model calibration and verification, and for development of pollutant loadings to the Passaic River and its tributaries. A separate Hatch Mott MacDonald (formerly Killam Associates) work plan describes the locations and devices used for this effort.[5] Since the City of Newark conducted its own program separate from this work effort, the program focused on four of the five municipalities operating combined sewer systems: Paterson, Kearny, Harrison, and East Newark. Forty-two (42) CSO drainage basins were identified and selected for monitoring in the four municipalities. Flow monitoring was conducted at the inlet to regulator chambers, or at the first upstream manhole, to monitor flow entering the regulators from CSO drainage basins. The City of Paterson also has approximately twenty internal relief points within three drainage basins of their combined sewer system that overflow to combined sewers discharging to the Passaic River or its tributaries. Two of the drainage basins were monitored under this baseline-monitoring program. Monitoring devices were installed at Market Street and Curtis Place in Paterson. The third basin, Montgomery Street (Loop Road) was monitored during a separate, later work effort described in the Hatch Mott MacDonald work plan. Thirty days of flow monitoring was conducted at each of the forty-four locations on a rotational basis in the period from April 1997 through August 1998. Water quality data was also collected for characterization purposes. A separate data report describes this program's methodology, sampling locations, and results, which includes water quality and flow data.[7] Table 3-3 provides flow summaries of the baseline monitoring program which was used in determining the component dry weather flow contributions from individual regulator drainage areas into the PVSC Interceptor Sewer System.

### 3.3 COMBINED SEWER OVERFLOW DATA

Hatch Mott MacDonald monitored nine CSO outfalls within the municipalities of Paterson, Kearny and Harrison during the period from January 1999 through December 2001. Based on the approved Work Plan[5], wet weather monitoring was conducted in six drainage basins including: in the City of Paterson Outfalls P-006 (Montgomery Street), P-025 (10th Avenue & 33rd Street), P-027 (Market Street), P-029 (Loop Road) and P-030 (19th Avenue); in the Town of Harrison Outfall H-007 (Worthington Avenue); in the Town of Kearny Outfalls 006 (Johnston Avenue) and K-007 (Ivy Street);

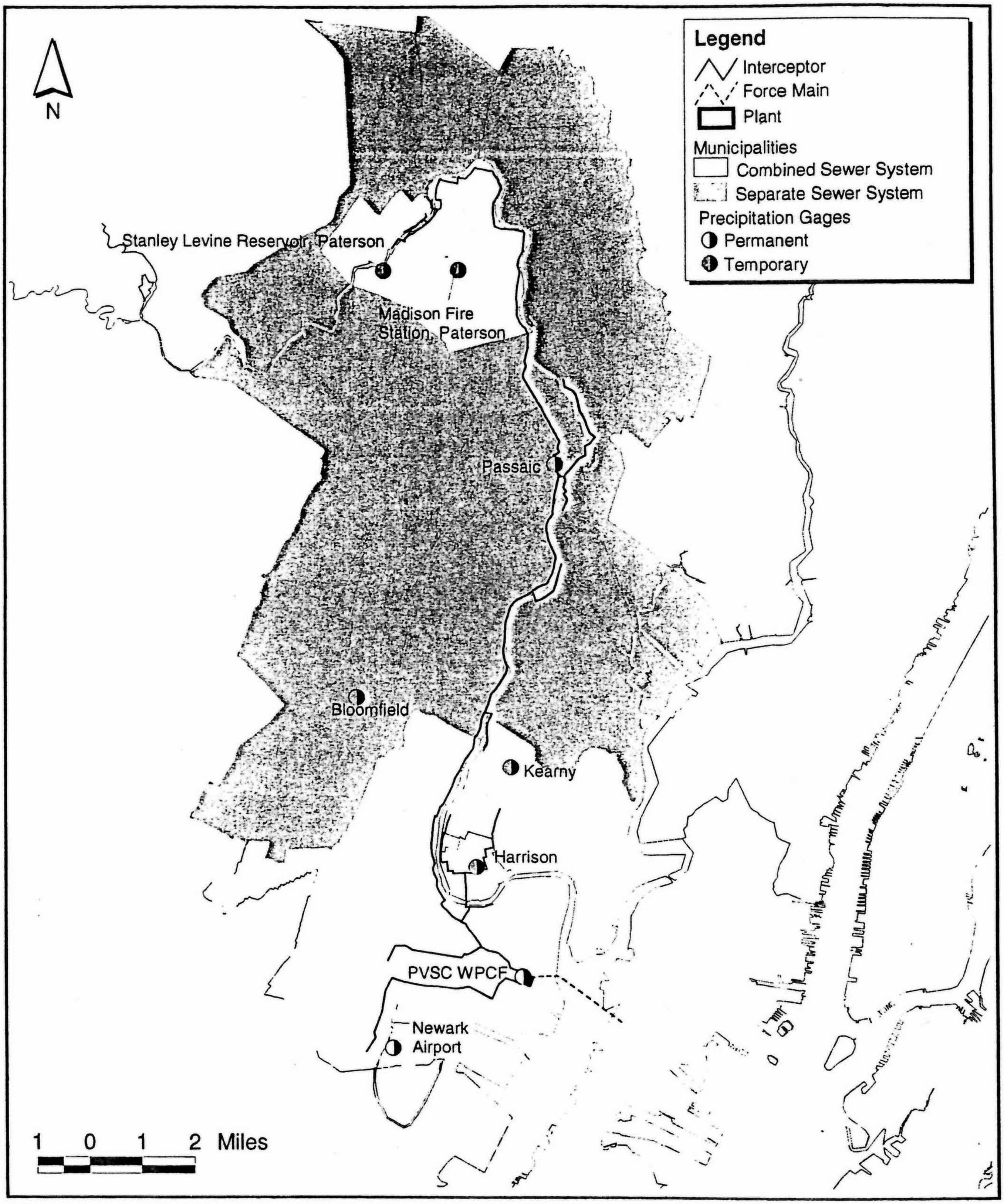
and in the Town of East Newark Outfall E-001 (Central Avenue). Water quality data was not monitored at the East Newark outfall.

Wet weather monitoring in the southern part of the project area which comprises the municipalities of Kearny, Harrison and East Newark was completed in 1999, while the monitoring in the City of Paterson was conducted in 2000 and 2001. The wet weather events in Kearny, Harrison and East Newark include: April 9, April 20 and September 30, 1999. Monitoring events in the City of Paterson include: November 11, 2000, March 21, 2001 and December 28, 2001. The overflow volumes and water quality data are well summarized in a previous report by Hatch Mott MacDonald[7].

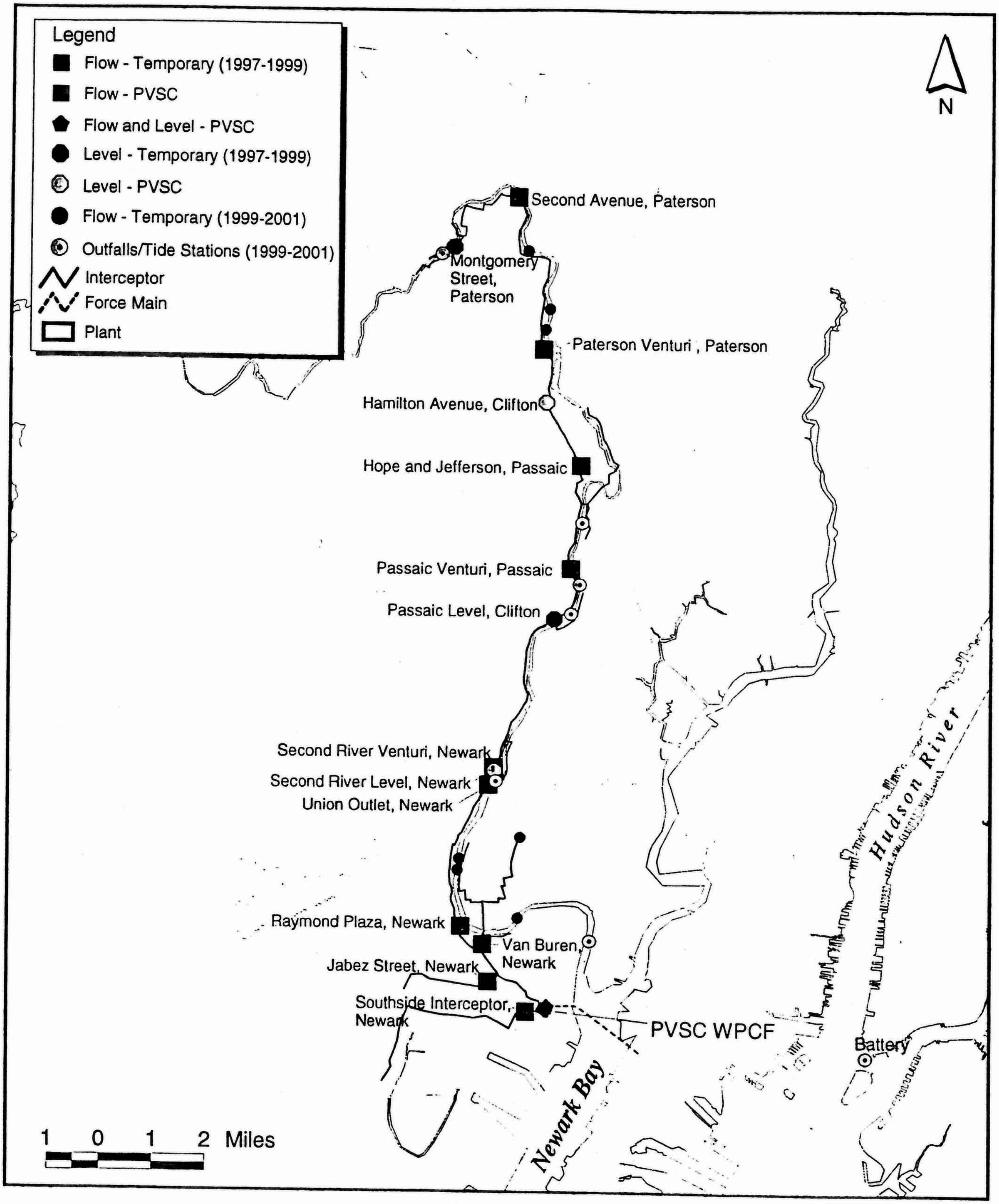
Limited in-system monitoring data, such as PVSC WPCF inflow and Paterson and Passaic Venturi meters, were available to supplement the overflow data. These overflow and in-system data together were used for the six wet weather events in the 1999-2001 period used for model calibration and verification.

**Table 3-3. PVSC Baseline Monitoring Summary**

| Location | City/Town | Daily Average Flow (MGD) Overall | Dry Weather | Wet Weather |
|---|---|---|---|---|
| Curtis Place | Paterson | 4.990 | 4.986 | 4.995 |
| McBride Avenue | Paterson | 0.774 | 0.757 | 0.800 |
| JFK HS 1 | Paterson | 2.366 | 2.364 | 2.368 |
| JFK HS 2 | Paterson | 1.850 | 1.865 | 1.827 |
| Sherwood Avenue | Paterson | 1.468 | 1.435 | 1.511 |
| Mulberry Street | Paterson | 0.000 | 0.000 | n/a |
| W. Broadway | Paterson | 0.044 | 0.033 | 0.094 |
| Bank Street | Paterson | 0.000 | 0.000 | n/a |
| Bridge Street | Paterson | 0.000 | 0.000 | n/a |
| Montgomery Street | Paterson | 2.493 | 2.231 | 2.844 |
| Straight Street | Paterson | 0.993 | 0.860 | 1.290 |
| Franklin Street | Paterson | 0.006 | 0.004 | 0.015 |
| Keen Street | Paterson | 0.204 | 0.183 | 0.270 |
| Warren Street | Paterson | 0.793 | 0.743 | 0.994 |
| Sixth Avenue | Paterson | 0.000 | 0.000 | n/a |
| E.Fifth Street | Paterson | 0.223 | 0.225 | 0.218 |
| E.Eleventh Street | Paterson | 0.993 | 0.946 | 1.172 |
| E.Twelfth Street | Paterson | 0.236 | 0.176 | 0.395 |
| S.U.M. Park | Paterson | 0.578 | 0.547 | 0.698 |
| Northwest Avenue | Paterson | 2.748 | 2.473 | 3.115 |
| Arch Street | Paterson | 0.358 | 0.064 | 0.876 |
| Jefferson Street | Paterson | 0.807 | 0.739 | 1.012 |
| Stout Street | Paterson | 0.000 | 0.000 | n/a |
| N.Straight Street | Paterson | 0.448 | 0.386 | 0.569 |
| Bergen Street | Paterson | 0.048 | 0.051 | 0.039 |
| Short Street | Paterson | 0.066 | 0.055 | 0.113 |
| Second Avenue | Paterson | 0.796 | 0.768 | 0.913 |
| Third Avenue | Paterson | 0.465 | 0.433 | 0.587 |
| 10th Ave. and E.33rd St. | Paterson | 3.298 | 3.022 | 5.965 |
| Twentieth Avenue | Paterson | 0.208 | 0.180 | 0.287 |
| Market Street | Paterson | 10.111 | 9.750 | 12.495 |
| Michigan Avenue | Paterson | 1.147 | 1.117 | 1.357 |
| Alabama Avenue | Paterson | 0.056 | 0.041 | 0.158 |
| Nineteenth Avenue | Paterson | 5.036 | 4.865 | 6.187 |
| Twentieth Avenue | Paterson | 2.182 | 1.994 | 3.406 |
| Route 20 Bypass | Paterson | 1.100 | 1.031 | 1.448 |
| Stewart Avenue | Kearny | 0.087 | 0.050 | 0.186 |
| Washington Avenue | Kearny | 0.146 | 0.099 | 0.234 |
| Bergen Avenue | Kearny | 0.000 | 0.000 | n/a |
| Nairn Avenue | Kearny | 0.193 | 0.107 | 0.336 |
| Marshall Avenue | Kearny | 0.114 | 0.019 | 0.264 |
| Johnston Avenue | Kearny | 1.562 | 1.240 | 2.349 |
| Ivy Street | Kearny | 2.427 | 1.751 | 3.931 |
| Bergen Avenue | Kearny | 0.487 | 0.413 | 0.659 |
| Tappan Street | Kearny | 0.152 | 0.108 | 0.255 |
| Dukes Street | Kearny | 0.256 | 0.190 | 0.390 |
| Cental Ave | E Kearny | 0.093 | 0.050 | 0.166 |
| Hamilton Street | Harrison | 0.032 | 0.015 | 0.107 |
| Cleveland Avenue | Harrison | 0.095 | 0.087 | 0.136 |
| Harrison Avenue | Harrison | 0.428 | 0.261 | 1.262 |
| Dey Street | Harrison | 0.000 | 0.000 | n/a |
| Middlesex Street | Harrison | 0.525 | 0.332 | 0.748 |
| Bergen Street | Harrison | 0.508 | 0.322 | 0.722 |
| Worthington Avenue | Harrison | 0.389 | 0.184 | 0.584 |




**Locations of Precipitation Monitoring Stations**




## Locations of Hydraulic Monitoring Stations

# Section 4

# SECTION 4

# INTERCEPTOR MODEL DEVELOPMENT

A mathematical model has been constructed representing the PVSC Interceptor Sewer System. This effort included selecting an appropriate modeling framework, reviewing various sources of information on the interceptor sewer system, conducting data analyses for selecting appropriate model parameters, and selecting appropriate conditions for substantiating the validity of the model. The following section describes these efforts, which produced a calibrated and verified model of the PVSC Interceptor Sewer System.

## 4.1 MODELING FRAMEWORK

The primary objective of this effort is to construct a model of the PVSC Interceptor Sewer System. The model will be used for evaluating current sewer system flow and solids transport capacity and future design alternatives. The modeling framework used in this effort is based on the U.S. Environmental Protection Agency's Storm Water Management Model (SWMM). This comprehensive mathematical model has both design and planning capabilities. SWMM is a dynamic rainfall-runoff simulation model, primarily but not exclusively for urban areas, capable of performing single-event or long-term simulations. The model is composed of several separate modules, or blocks, for simulating hydrology, sanitary flow, flow routing through the sewer systems, storage, and treatment. These blocks can be run in sequence or independently. Flow routing is performed for surface and sub-surface conveyance and groundwater systems. It is a time-variable model capable of calculating flow and hydraulic grade lines. Several third-party software vendors market SWMM packages that provide graphical user interfaces, post-processing utilities, and other enhancements that greatly improve the usability of SWMM. These packages essentially use the original SWMM as their computational engine.

A third-party software package called XP-SWMM, distributed by XP-Software, Inc., was used for constructing the PVSC interceptor sewer model. This software package uses a state-of-the-art graphical user interface with greater flexibility and libraries of information for constructing a model. Post processing tools are provided for quickly analyzing model calculations. Using the SWMM engine, this package solves the complete St. Venant (dynamic flow) equations during hydraulic calculations in the sewer network, which includes modeling backwater effects, flow reversal, surcharging, looped connections, pressure flow, tidal outfalls, and real-time control. The SWMM blocks used in this analysis were Runoff for hydrology, Transport for sanitary flow simulation, and Extran for dynamic flow routing in the interceptor sewer system.

The model of the PVSC Interceptor Sewer System was constructed using information previously reported for PVSC. The physical information used to build the model was extracted from a PVSC Combined Sewer System Facilities Inventory and Assessment Analysis.[8] The information provided in this report includes invert and ground elevations of manholes, pipe dimensions, and regulator configuration and dimensions. Hydraulic grade line calculations are required to evaluate surcharging under high flow conditions. Therefore, all vertical elevations were specified with reference to 100 feet below mean sea level at Sandy Hook, New Jersey, which is the vertical datum used on all PVSC interceptor sewer descriptions.

The primary focus of developing the model is the interceptor sewer itself. However, in combined sewer areas flow primarily enters the interceptor sewer system through regulators. Therefore, regulators are simulated by modeling one conduit immediately upstream of the regulator, the weir/orifice controlling flow within the regulator, its overflow discharge conduit, and its connection to the interceptor sewer. Internal reliefs in Paterson are simulated in a similar fashion. Sanitary connections to the interceptor sewer are simulated with manholes at the junction at which the sanitary flow enters the system. Conduits in the system are primarily modeled from manhole to manhole when changes in pipe characteristics occur. The model simulates Paterson conduits from manhole to manhole to specifically assess flow and potential flooding conditions.

The model simulates PVSC Interceptor Sewer System starting at River and Prospect Streets in Paterson and terminating at the Forebay in the headworks of PVSC WPCF. Several branch interceptor sewers are simulated. The Lawrence Street branch interceptor sewer is modeled starting at the intersection of Presidential Boulevard and Northwest Avenue in Paterson. The Jabez Street branch interceptor sewer is modeled starting at Wheeler Point Road and South Bay Avenue in Newark. The Kearny-North Arlington branch interceptor sewer starts at the intersection of Passaic and Washington Avenues in Kearny. The Kearny-Harrison-Newark branch interceptor sewer starts at the intersection of Schuyler Road and King Street in Kearny. The Kearny-East Newark-Harrison branch interceptor sewer starts at the intersection of Passaic and Nairn Avenues in Kearny. The South Side Interceptor Sewer is also simulated starting from U.S. Routes 1 and 9 near Waverly Ditch and terminating at the Main Interceptor Sewer. The PVSC interceptor sewer model currently consists of 933 nodes and 933 pipes.

## 4.2 HYDROLOGY CALCULATIONS

The Runoff block of SWMM performs rainfall-runoff calculations for drainage basins. It simulates a drainage basin as a collection of subcatchments - each representing idealized runoff areas with uniform physical characteristics such as surface roughness, percent imperviousness and ground

slope. Detailed meteorological data and surface characteristics are required as model input to generate runoff hydrographs from each of the subcatchment areas. These runoff hydrographs can be used as direct input for another SWMM block, such as Transport and Extran, where wet weather runoff flows are distributed to specified nodes in the model representing inlet points in the collection system, or they can be used as input to a receiving water model when the nodes represent CSO outfall locations.

Surface characteristics required for input to the SWMM Runoff block define each subcatchment and provide information necessary to calculate and route runoff flows. Each subcatchment is assigned parameters to characterize the subcatchment area. Characteristic parameters such as drainage area, land slope, width of overland flow, and Manning's surface roughness coefficients are used to calculate the velocity of overland runoff flow. Infiltration, evaporation, depression storage, and percent imperviousness are used to calculate the volume of runoff flow. These parameters are selected through evaluations of various sources such as aerial photographs, topographic maps, field verifications, or published literature.

Calculations by the Runoff block are executed for each subcatchment, which is conceptualized as a non-linear reservoir (Figure 4-1). The subcatchment is filled with an applied rainfall to an initial subcatchment volume, which is first reduced by infiltration and evaporation. The remaining volume is then used to calculate the subcatchment outflow.

For each modeled subcatchment, the Runoff block requires meteorological data consisting of precipitation hyetographs and, optionally, wind speeds and air temperatures. The data may be real or hypothetical, but should be as representative as possible for each subcatchment area and for the conditions being modeled. Since single storm cells can be about one square mile in size, spatial variations in precipitation can significantly affect runoff patterns, especially in larger drainage areas. Precipitation data were collected from the six temporary and two permanent monitoring devices (Section 3.1). Preliminary analyses of the data collected by these devices indicated that variations in precipitation between devices appeared significant. Therefore, data from three temporary and one permanent devices were assigned to particular drainage areas, namely, Paterson, Kearny, Harrison, and Newark. This is further described in Section 5 describing calibration and verification. Precipitation data was applied to the interceptor sewer model in hourly increments.

Evaporation is subtracted from rainfall intensities in the Runoff block at each time step and is also used to replenish depression storage and provide an upper bound for soil moisture and groundwater evaporation.[9] Single event simulations are usually insensitive to the evaporation rate; even though evaporation can make up a significant component of the mass balance during a continuous simulation. A model default evaporation rate of 0.1 in/day was used in the interceptor sewer model

since local data was unavailable. Typical evaporation rates observed in nearby municipalities such as New York City range anywhere from 30 to 45 inches per year. Therefore, a rate of 0.1 in/day was found very reasonable.

The Runoff block provides optional methods of calculating infiltration in pervious areas. The Horton infiltration equation, which is most commonly used, was chosen for application to the interceptor sewer model. Infiltration is calculated in the model as a function of time and parameters describing soil conditions as follows:

$$f_p = f_c + (f_o - f_c)\, e^{-kt}$$

Where:

| | | |
|---|---|---|
| $f_p$ | = | infiltration capacity of soil at time t (ft/sec), |
| $f_c$ | = | minimum or ultimate value of $f_p$ (ft/sec), |
| $f_o$ | = | maximum or initial infiltration capacity (ft/sec), |
| t | = | time from beginning of event (sec), and |
| k | = | decay coefficient (sec-1). |

Soil characterization data of the PVSC service area was not available for selecting site-specific infiltration parameters. However, the watershed management characterization report prepared by Hatch Mott MacDonald (formerly Killam Associates)[15] shows that the general soil distribution includes hydrologic soil types A, B and C, with type A having higher infiltration rates and type C having lower infiltration rates. Therefore an initial assignment of Horton equation parameters was based on an assumption that service area soils have equal distribution of soil types A, B and C. Taking guidance from the literature, the parameters were initially assigned in the model as 3.0 inch/hour for the maximum infiltration rate, 0.3 inch/hour for the minimum infiltration rate, and 0.00115 for the decay coefficient. These parameters were then adjusted during the wet weather calibration process.

Manning's equation, in the following form, is used by the model to calculate outflow from each subcatchment area:

$$Q = W\frac{1.49}{n}(d - d_p)^{5/3} S^{1/2}$$

Where:

| | | |
|---|---|---|
| Q | = | subcatchment runoff (cubic feet per second [cfs]), |
| W | = | subcatchment width or width of overland flow (ft), |
| n | = | Manning's roughness coefficient, |

| | | |
|---|---|---|
| d | = | water depth of rainfall and snowmelt (ft), |
| $d_p$ | = | depression storage depth (ft), and |
| S | = | land slope (ft/ft). |

Information used to assign these parameters for each subcatchment was extracted from data developed and reported by Hatch Mott MacDonald.[1] This report provides the drainage area, ground slope, overland flow width, subcatchment length, and imperviousness values for each PVSC regulator drainage basin. Depression storage is a volume that must be filled prior to the occurrence of runoff on both pervious and impervious areas. Assumptions used to select infiltration parameters were also applied to select depression storage parameters. Typical values of 0.1 and 0.01 inches were used to represent depression storage in pervious and impervious areas, respectively. Simulation of depression storage by the model also requires input of Manning's roughness coefficient and impervious area percent-of-zero-detention, which is a portion of the impervious area that is assigned zero depression storage in order to promote immediate runoff. Typical values of 0.014 and 0.2 were used to represent Manning's surface roughness coefficient for impervious and pervious areas, respectively. A typical value of 25% was assigned for percent-of-zero-detention for impervious areas. The data provided in Hatch Mott MacDonald[1] were used as an initial set of model parameters. Based on further review of aerial photographs of the study area, the parameters were locally adjusted during the calibration process. Table 4-1 summarizes the calibrated hydrologic model parameters for individual drainage areas.

## 4.3 SANITARY FLOW CALCULATIONS

The Transport block of SWMM calculates sanitary flow, combines it with runoff flow computed in the Runoff block, and routes the combined flow by solving a non-linear kinematic wave equation. However, the transport block cannot model reverse flow or backwater effects. Sanitary flow enters a sewer system at any node in SWMM using several methods. It can be specified using a constant flow (e.g., a calculated daily average). A time-variable flow can be specified simulating the typical diurnal nature of sanitary flow. It can also be computed by SWMM using regression equations with specifications for residential landuse, which requires specifying parameters such as population density. The time-variable method was used in the PVSC Interceptor Sewer Model. Diurnal variations in sanitary flows were characterized using the baseline monitoring data. The SWMM model can include diurnal, weekly, and seasonal variations in sanitary flows, however, for model simplification, one set of diurnal factors was used for sanitary flows coming in from each major municipality, namely, Kearny, Harrison, and Paterson.

## Table 4.1 Calibrated Hydrologic Model Parameters

| Subbasin | Area (acre) | Percent Imperviousness (%) | Infiltration (inch/hr) | | Depression Storage (inch) | | Surface Roughness | | Evaporation (inch/day) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Maximum | Minimum | Impervious Area | Pervious Area | Impervious Area | Pervious Area | |
| CS34 | 831 | 35.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS45 | 208 | 42 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS44 | 38 | 60 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS31 | 157 | 36 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS33 | 250 | 51 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS41 | 84 | 52.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS43 | 64 | 64.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS35 | 58 | 42 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS57A | 90 | 62.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS58 | 189 | 59.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS59 | 116 | 57 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS32 | 19 | 50.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS38 | 55 | 57.75 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS39 | 7 | 28.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS40 | 16 | 44.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS42 | 2 | 74.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS36 | 54 | 39 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS37 | 18 | 40.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| R01 | 3.05 | 22.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS15 | 47 | 32.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS05 | 15 | 51 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS16 | 243 | 35.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS07 | 84 | 25.35 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS09 | 17 | 28.76 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS10 | 104 | 26.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS21 | 11 | 24.86 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS22 | 32 | 29.74 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS11 | 41 | 33.64 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS13 | 103 | 26.63 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS14 | 25 | 33.15 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS23 | 26 | 41.48 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS24 | 66 | 39.38 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS26 | 62 | 27.3 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| R27 | 123.72 | 24.38 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS02 | 2 | 57 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS03 | 4 | 62.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS04 | 15 | 51 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS08 | 2 | 15.11 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS12 | 8 | 33.64 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS46 | 369 | 37.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS83 | 484 | 70 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS60 | 1745 | 38.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS61 | 541 | 14.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS62 | 316 | 41.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS28 | 39 | 54 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS29 | 10 | 54 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS17 | 32 | 32 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS20 | 82 | 35.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS18 | 38 | 35 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS19A | 15 | 35.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| A1-1 | 206.73 | 20 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-3 | 177.25 | 20 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |

# Table 4-1. Calibrated Hydrologic Model Parameters (Continued)

| Subbasin | Area (acre) | Percent Imperviousness (%) | Infiltration (inch/hr) | | Depression Storage (inch) | | Surface Roughness | | Evaporation (inch/day) |
|---|---|---|---|---|---|---|---|---|---|
| | | | Maximum | Minimum | Impervious Area | Pervious Area | Impervious Area | Pervious Area | |
| CS20 | 82 | 35.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS18 | 38 | 35 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS19A | 15 | 35.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| A1-1 | 206.73 | 20 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-3 | 177.25 | 20 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-8 | 20.39 | 22.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-6 | 11.01 | 22.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-5 | 210.6 | 20 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-4 | 4.8 | 22.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSA1-7 | 24.9 | 22.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS48 | 240 | 33 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS50 | 200 | 39 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS76 | 27 | 42 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS51 | 1740 | 42 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS54 | 128 | 58.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS55 | 288 | 51.75 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS49 | 3 | 36.75 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS52 | 8 | 70.5 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS53 | 10 | 62.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS47 | 55 | 51 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS56 | 396 | 59.25 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-7 | 19 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-8 | 250 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-3 | 0.4 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-2 | 12 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-1 | 91 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-4 | 14 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-5 | 62 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-6 | 18 | 50 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV1-9 | 188.24 | 24.38 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSV2-1 | 792.98 | 24.38 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS25 | 714 | 35 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CS06 | 40.02 | 35 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSEF-2 | 13.26 | 55 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSEF-6 | 219.76 | 60 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSEF-4 | 45.68 | 55 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSEF-5 | 15.23 | 55 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |
| CSEF-3 | 32.18 | 55 | 2 | 0.3 | 0.01 | 0.1 | 0.014 | 0.2 | 0.1 |

### 4.3.1 Baseline Sanitary Flow Selection

The time-variable method provides a simple mechanism to simulate sanitary flow, which normally exhibits a diurnal pattern especially in residential-dominated service areas. A daily average flow is assigned to each sanitary flow entry point in the model. The average flow is then adjusted on an hourly basis using percentages (above and below 100 percent) to simulate the diurnal sanitary trend over a 24-hour period. Diurnal sanitary flows were simulated in the model for all subcatchments, combined and separate. Sanitary flows for combined areas were specified at manholes immediately upstream of the regulators. Sanitaiy flows in separately sewered areas were entered at branch lines to the Main Interceptor Sewer simulating their entry points to the system. Statistical analyses of data collected during field investigations and from PVSC system monitoring provided the information necessary to select average flows and hourly adjustment factors for the diurnal calculation in the model.

Hourly WPCF flow data recorded by PVSC was reviewed for the period of January 1992 through November 1998 to determine the overall dry weather flow characteristics of the interceptor sewer system. Using the EWR and Little Falls rainfall records, flow data was stripped from the record for days on which precipitation was measured and for the following day. Stripping the day following a wet weather event takes into consideration the precipitation events having residual flow effects on subsequent days. The data was then reduced to monthly average flows to determine trends in monthly flow. Analysis of the data indicates that the monthly average dry weather flow is 268 million gallon per day (MGD).

The JCSA/Bayonne Force Main (serving Jersey City, South Kearny, and Bayonne) is not explicitly represented in the model. Therefore, JCSA/Bayonne Force Main flow data must be subtracted from total WPCF flow when the interceptor sewer system flow calculations are compared to data. An analysis was conducted of data recorded for the JCSA/Bayonne Force Main for the period of September 1997 through December 1998. This analysis indicated that the monthly averaged total flow is 57 MGD. Dry-weather data stripping, consistent with that performed with WPCF data, was conducted to identify the dry weather days. The analysis indicated that the pumped flow does not vary significantly with precipitation. These flow characteristics were considered when allocating dry weather flow throughout the interceptor sewer system.

The analysis of WPCF and JCSA/Bayonne Force Main data provided the necessary information to develop a baseline diurnal flow function for the entire interceptor sewer system. The average total dry weather flow to the PVSC WPCF is 268 MGD and the average force main flow is 57 MGD. Therefore the monthly average dry weather or sanitary flow from the Main and South Side Interceptor Sewers is 211 MGD.

The main purpose of this modeling effort is to construct a model of the interceptor sewer system itself including individual regulators. In order to accurately model hydraulics in the Main and South Side Interceptor Sewers, sanitary and wet weather flows must be assigned to enter the interceptor sewer system at appropriate points and with appropriate characteristics. Having determined the overall dry weather flow characteristics for the interceptor sewer system, sanitary flow was then allocated within the model at various entry points representing combined or sanitary connections.

Field investigations described in Section 3.2.2 included the baseline monitoring of individual regulators for a minimum of 30 days each in four separate municipalities including Paterson, Kearny, Harrison, and East Newark. Meters were installed to monitor flow entering the regulators from their CSO drainage basins. Flow data was reported as average daily flow during the entire monitored period and broken down by dry and wet weather periods. Additional flow monitoring was conducted at Market Street and Curtis Place in the Paterson internal relief systems. The objectives of this monitoring program included a development of dry and wet weather quantity and quality data for use in this study focusing on individual CSO drainage areas. However, the data proved very helpful in determining average dry weather flows and diurnal characteristics for the monitored regulators. These data were used as initial sanitary flow specifications to be adjusted by the model with a diurnal function. The sanitary flow specifications were later refined during the model calibration process.

Baseline monitoring data was not collected in the City of Newark. Sanitary flow specifications for Newark combined sewer drainage areas were therefore developed from alternative sources. Sanitary flows were initially selected using information documented in a 1976 overflow analysis.[10] These data were compared to calculations performed using more recent landuse data.[1] Finally, monitoring data collected during an ongoing project being conducted by the City of Newark[11] were used to further adjust sanitary flows. This information was used for specifying initial sanitary flows that were adjusted by the diurnal function in the model. The sanitary flow specifications were later refined during the model calibration process.

There are numerous separately sewered municipalities and industries connected to the PVSC Interceptor Sewer System. Figure 4-2 presents the names and locations of these connections to the interceptor sewer system as they are modeled. Sanitary flow rates for separate sewer lines were taken from average weekly flows metered by PVSC, which was previously discussed in Section 3.2.1. These data were used as initial sanitary flow specifications to be adjusted by the model by the diurnal function. The sanitary flow specifications were later refined during the model calibration process.

In addition to the uncertainty in sanitary flow estimates, the separately sewered municipalities experience a moderate to significant amount of inflow and infiltration. Infiltration primarily occurs through seepage of groundwater through the cracks and joints in the sewer system, and is very season

dependent. On the other hand, inflows such as roof leader flows can occur throughout the year and can coincide with the timing of runoff flows discharged into the sewer system from the individual drainage areas. The infiltration/inflow (I/I) components are often characterized by practitioners by adding small drainage areas to the separately sewered areas so that the runoff from this drainage area being represented explicitly as I/I or by increasing dry weather flows with a peaking factor multiplied to the dry weather flows from separately sewered areas. In this study, I/I is modeled with peaking factors for individual separately sewered drainage areas. Hatch Mott MacDonald[12] describes the I/I analysis performed for selected drainage areas in the Towns of Belleville, Bloomfield and Harrison; Cities of Clifton, East Orange, and Garfield; Boroughs of East Newark, Elmwood Park, Fair Lawn, Glen Ridge, Glen Rock, Haledon, Hawthorne, and East Rutherford. This I/I data were reviewed to determine the initial set of peaking factors, which were then adjusted during the model calibration process.

### 4.3.2 Diurnal Function Selection

An analysis of dry weather flow data from the baseline regulator monitoring, the WPCF, and the JCSA/Bayonne Force Main indicated a variation of hourly flow from town to town, and prompted the need to use multiple diurnal curves to better simulate sanitary flow in the interceptor sewer system. For instance, hourly flow characteristics for the City of Newark, with industrial and residential landuses, differs from that of Paterson, Kearny, and Harrison, which are mostly residential. This is critically important due to the large service area and the extensive length of the interceptor sewer system, which affects calculations influenced by time of travel through the system. The SWMM framework provides for input specifications of individual diurnal functions, which was employed for the PVSC interceptor sewer model.

Using PVSC WPCF data reduced to hourly intervals, further analyses characterized its diurnal function for an average dry weather day. Figure 4-3 presents this diurnal function based on a daily average total flow of 268 MGD, which includes the JCSA/Bayonne Force Main. Flow data typically varies from a minimum of 192 MGD at 6:00 a.m. to a maximum of 308 MGD at 3:00 p.m. This diurnal function was initially applied to the entire service area but did not accurately reproduce monitoring data during the calibration process. Diurnal flow functions were therefore developed using dry weather flow data from hydraulic monitoring meters at Second Avenue, Paterson Venturi, Union Outlet, Van Buren, Jabez Street, South Side Interceptor Sewer and PVSC WPCF. Analyses performed on monitoring data collected in Newark drainage areas indicated that a diurnal function does not exist. Therefore, constant flows were assigned to Newark with no diurnal variations.

### 4.3.3 Simulating Seasonal Variability

While conducting statistical analyses of PVSC WPCF data, it became apparent that variations exist in data. It was recognized that the monthly average dry weather flow of 268 MGD varied, on average, from a minimum of 250 MGD in September to a maximum of 293 MGD in April. These calculations include the JCSA/Bayonne Force Main. The JCSA/Bayonne Force Main flow also varied, on average, from a minimum of 53 MGD in October to a maximum of 64 MGD in April. Table 4-2 presents dry weather flow statistics for monthly and daily average PVSC WPCF and JCSA/Bayonne Force Main flows. The data generally follow a seasonal trend.

The apparent seasonal variation of sanitary flow in PVSC service areas prompted the development and use of an average-month flow for combined and separate subcatchments. A relationship was developed, subsequent to calibrating the model to dry weather flows, to compute the daily average sanitary flow for each drainage area given the total flow and the force main flow. To simulate interceptor sewer flow for a given month, the mean monthly WPCF flow is selected from that shown in Table 4-2. All sanitary flows entering the interceptor sewer system are then scaled as a function of the chosen monthly flow to the overall average flow of 268 MGD.

## 4.4 FLOW ROUTING CALCULATIONS

The Extran block of SWMM solves the complete St. Venant dynamic flow equations throughout a simulated sewer system and models backwater effects, flow reversal, surcharging, looped connections, pressure flow, tidal outfalls, and real-time control. Extran extends calculations of the Transport block using hydrologic flows calculated in Runoff and sanitary flows calculated in Transport to perform dynamic routing of flows in the regulators and through the Interceptor Sewer System to the PVSC WPCF. Weir elevations and other regulator configurations are specified in the model to perform dynamic calculations beyond simply specifying regulator capacities. Backwater, surcharging, and other conditions influence calculations to determine combined sewer overflows and routing to the interceptor sewer system. Simulation output provides time-varying water surface elevations and flow rates at selected locations.

Simulations of regulator devices in the PVSC Interceptor Sewer System include a regulator, one manhole upstream of the regulator for entry points of sanitary flow and runoff, an orifice and connecting pipe to convey underflow from the regulator to the interceptor sewer, a weir to determine overflows based on hydraulic elevations in the regulator chamber, and an outfall point for combined sewer overflows. Figure 4-4 provides a schematic representation of how flow regulation is simulated in the PVSC Interceptor Sewer System. The interceptor sewers are simulated from manhole to manhole

Table 4-2. PVSC WPCF Monthly Dry Weather Flow Statistics

DRY WEATHER FLOW - Summary (Yrs. 1992-1998)

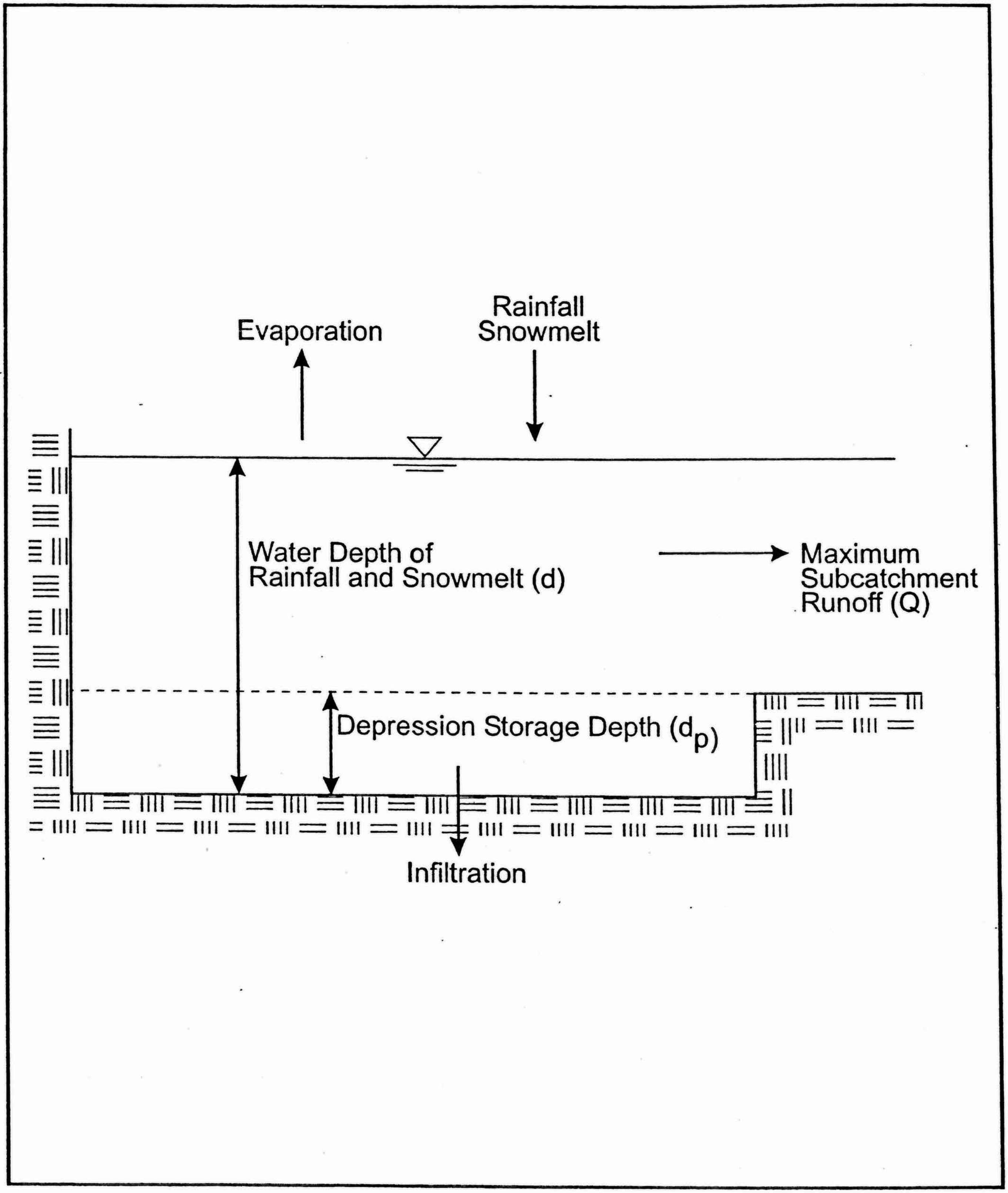
| | Monthly (MGD) | | | Daily (MGD) | | | Force main (1997-1998) Monthly Mean |
|---|---|---|---|---|---|---|---|
| Month | Average | Maximum | Minimum | Average | Maximum | Minimum | |
| January | 275.68 | 286.81 | 264.10 | 274.98 | 325.00 | 222.77 | 61 |
| February | 279.00 | 303.49 | 255.95 | 275.72 | 337.28 | 246.32 | 61 |
| March | 282.52 | 300.42 | 253.12 | 279.15 | 315.74 | 240.77 | 61 |
| April | 293.22 | 325.66 | 245.00 | 282.76 | 333.42 | 235.71 | 64 |
| May | 268.27 | 303.90 | 248.43 | 270.44 | 332.42 | 232.16 | 59 |
| June | 270.24 | 281.15 | 253.13 | 269.50 | 300.37 | 236.06 | 59 |
| July | 261.62 | 268.88 | 255.75 | 262.57 | 305.04 | 221.60 | 57 |
| August | 255.03 | 273.53 | 249.25 | 252.41 | 278.04 | 223.92 | 54 |
| September | 249.59 | 259.47 | 234.34 | 250.12 | 272.13 | 211.08 | 55 |
| October | 252.27 | 268.67 | 239.89 | 251.41 | 318.53 | 222.10 | 53 |
| November | 256.74 | 278.52 | 244.09 | 256.16 | 332.06 | 231.17 | 57 |
| December | 266.84 | 324.40 | 245.90 | 254.97 | 324.40 | 226.08 | 56 |
| Average | 268 | | | | | | 57 |
| Maximum | | 326 | | | 337 | | 53 |
| Minimum | | | 234 | | | 211 | 64 |

| | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1992-1998 |
|---|---|---|---|---|---|---|---|---|
| Annual Average | 259 | 267 | 269 | 254 | 269 | 263 | 267 | **264** |
| Max. Month | 281 | 326 | 303 | 279 | 324 | 299 | 304 | **326** |
| Max. Day | 302 | 332 | 337 | 309 | 331 | 333 | 332 | **337** |

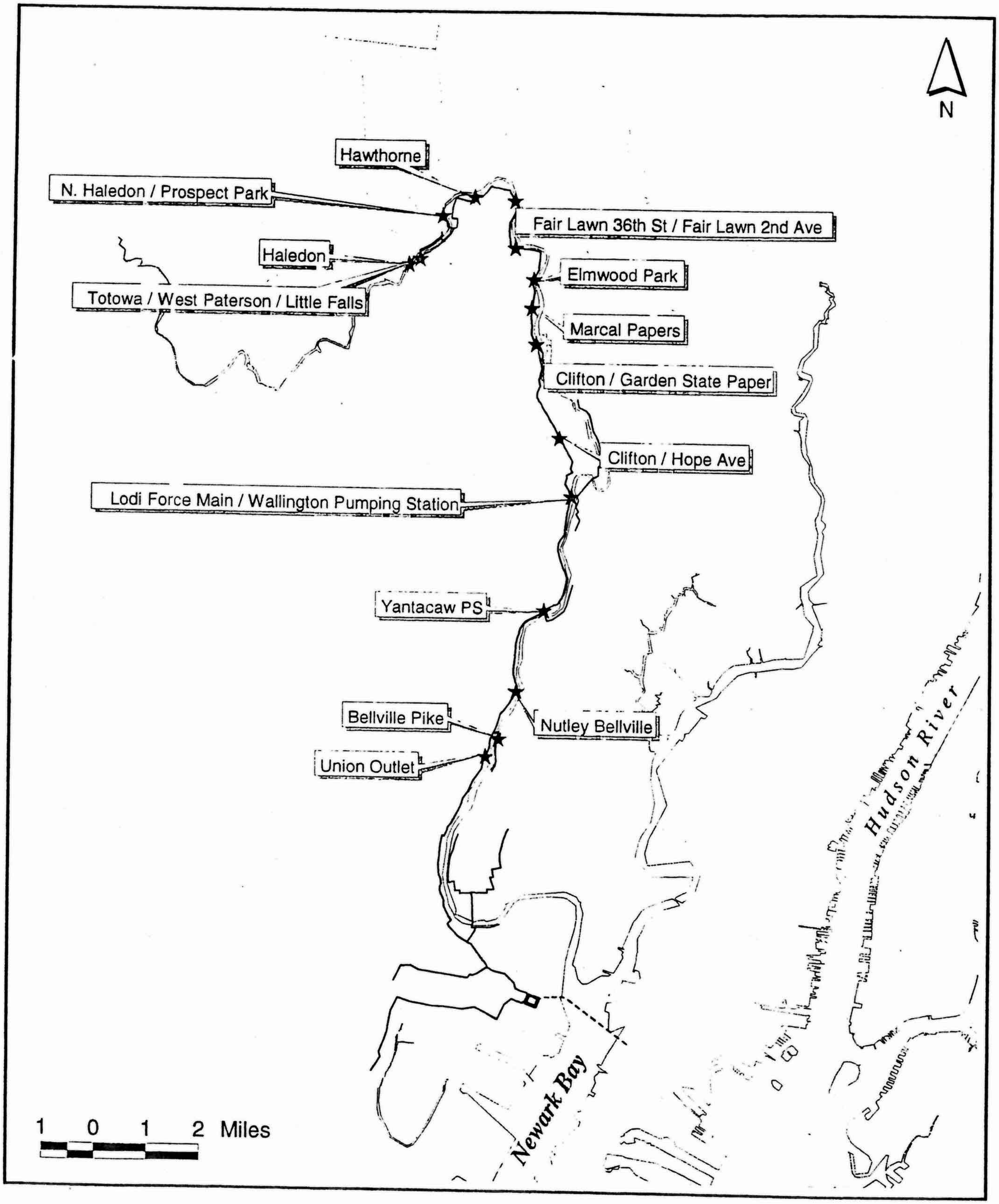
from the most upstream points in the Main and South Side Interceptor Sewers to the headworks of PVSC WPCF.

Pipe roughness coefficients are required to calculate pipe flow and hydraulic elevations. Therefore, roughness coefficients for interceptor sewers were specified using information previously developed for PVSC by Charles A. Manganaro Consulting Engineers during undocumented hydraulic evaluations of the interceptor sewer system. The literature and SWMM documentation suggest using roughness coefficients for concrete pipe generally varying from 0.011 to 0.016 with most values described between 0.013 and 0.014. Initial specifications of the coefficients consider changes in pipe direction, sizes, losses, etc., and generally range from 0.013 to 0.014. These values are consistent with the literature for the poured concrete pipe used to construct PVSC interceptor sewers. A select few pipes in the model have coefficients below this range, while values no higher than 0.014 were used. Default roughness values of 0.014 were assigned for side connections. All roughness coefficients were adjusted from initial specifications during calibration efforts, but remained within the ranges of reports and other literature.

Flow through an outfall is influenced significantly by the presence of tide gates and tidal levels in the Passaic River during overflow conditions. Under high tide levels and depending on hydraulic head in the interceptor sewer system, overflows can be restricted or entirely prevented. This can create a surcharge condition back through the discharge pipe, into the regulator, the interceptor sewer system and the combined sewer system that may result in street or basement flooding. Therefore, tide water levels are explicitly included in the model. Tidal data recorded at the Battery in Manhattan, New York by NOAA was used in developing corrected tide levels for the individual outfalls. Correction factors provided by NOAA for the Passaic River were used in this adjustment process. Water level data observed at the outfalls, when available, were also used to supplement the tide data adjusted based on Battery data.



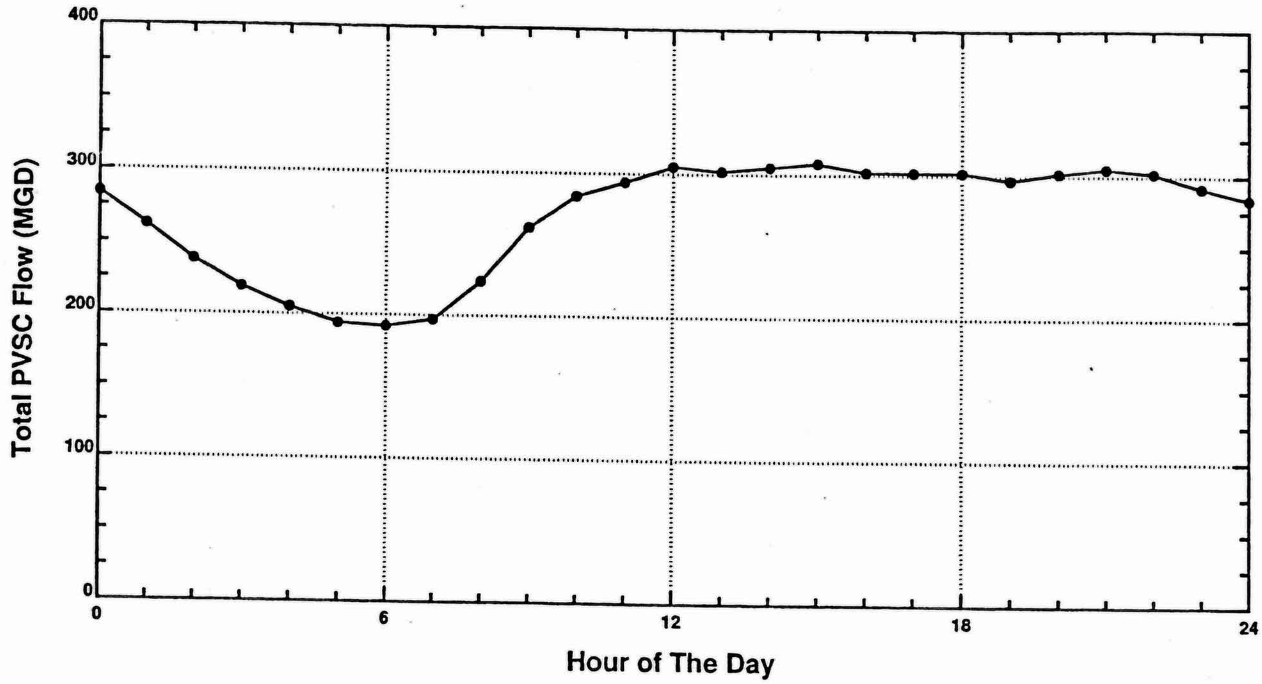

**Conceptual Representation of Subcatchment in Hydrology Calculations.**



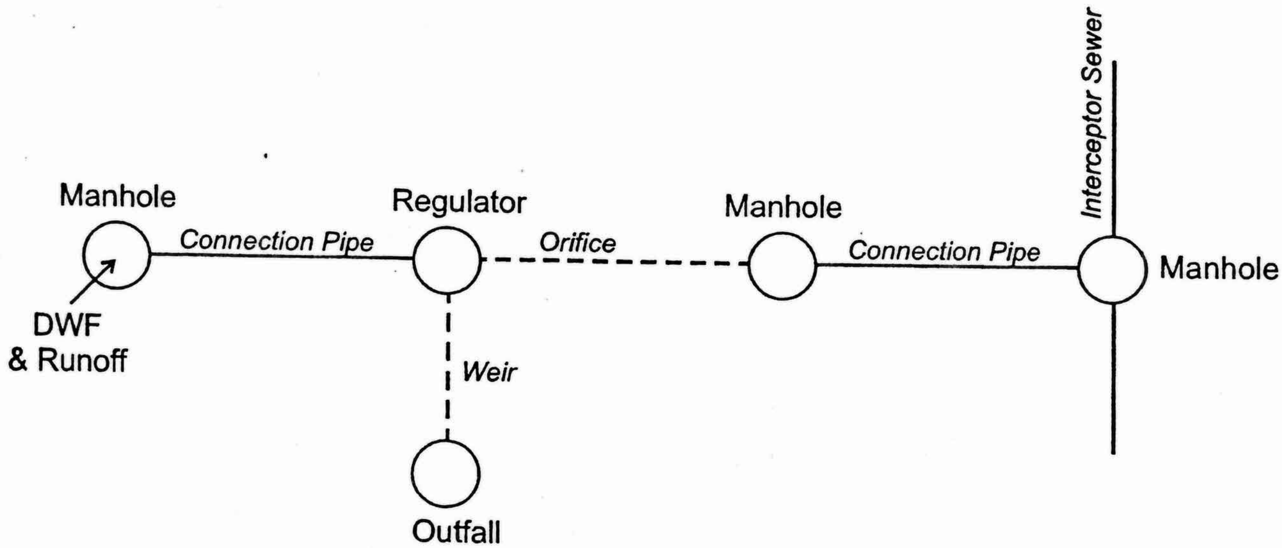

**Interceptor Connections From Major Separately Sewered Areas and Industries**

Passaic Valley Sewerage Commissioners

FIGURE 4-2




Interceptor Diurnal Flow at WPCF




**Typical Flow Regulation in Extran**

# Section 5

## SECTION 5

# MODEL CALIBRATION AND VERIFICATION

The accuracy and performance of a computer model is best measured by its ability to reproduce actual conditions it is attempting to simulate. A calibration and verification process first involves a selection of several simulation periods (events) for which data is readily available or has been collected. It is important to select periods that are also representative of the conditions that will be simulated by the model such as either typical or extreme rainfall events, or both, in addition to normal and/or seasonal dry weather conditions. Several periods can be selected during a calibration process such that model parameters are selected and adjusted to reasonably reproduce actual data within acceptable and justifiable model parameter ranges. The calibration process can result in several sets of model parameters that reasonably simulate individual events but may need to be combined to simulate various conditions that the model will be used to analyze. Therefore, verification periods are simulated once a final set of model calibration parameters has been selected. The accuracy and performance of the model can then be assessed by its ability to independently simulate verification periods without adjusting model parameters.

The PVSC interceptor sewer model was calibrated and verified using precipitation and hydraulic data collected under various sampling programs. The model calibration and verification applies to general reaches of the interceptor sewer system including individual regulators. At the onset of the calibration effort, it was recognized that a relationship exists between hydraulic conditions in the interceptor sewer system and conditions in the headworks of the PVSC WPCF. Therefore a function was established relating hydraulic elevations in the WPCF forebay to interceptor sewer flow conditions. Model calibration and verification then proceeded by selecting periods from program monitoring efforts using selection rationales that would be most appropriate for the eventual use of the model. Calibration and verification of the interceptor sewer model was then completed for several dry and wet weather simulation periods. This section describes these efforts and the final configuration of the PVSC Interceptor Sewer System model.

## 5.1 FOREBAY CALIBRATION

The water level in the forebay of the PVSC WPCF propagates back to the Interceptor Sewer System, and together with flow-related head losses, influences hydraulic conditions during high flow periods particularly in the Main Interceptor Sewer. Inspection of data for WPCF influent flows and hydraulic elevation measurements in the forebay indicated that forebay water elevations vary and can

be correlated to flow. A mathematical relationship between interceptor sewer system flow rate (Main and South Side combined) and forebay elevation was developed for use in the interceptor sewer model. PVSC-measured 2.5-minute flow and elevation data was analyzed for selected wet weather periods, chosen by reference to independent rain data for providing data at higher flow rates. The 2.5-minute data was reduced to hourly-averaged values for flow and forebay elevation, and all such pairs of hourly-averaged values in the pooled data set were subjected to a regression analysis. The results of this analysis indicated that there was a positive correlation between interceptor sewer flow (Q, in MGD) and forebay level (H, in feet), and provided the following equations characterizing the relationship for wet weather and dry weather conditions.

$$H = 0.0101Q + 80.141 \quad \text{(Wet)}$$

$$H = 0.0122Q + 80.128 \quad \text{(Dry)}$$

The PVSC forebay water elevation data ranged from 84.4 feet to 87.4 feet for influent flows of 300 to 600 MGD. These relationships had correlation coefficients of 0.99 and 0.96 for the wet and dry periods respectively. It should be noted that the available data and above relationships are based on the existing PVSC WPCF headworks. The SWMM framework provides for specifying relationships within the model for simulating conditions such as the PVSC forebay hydraulics. The interceptor sewer model uses the above equations for predicting elevations in the forebay as a function of flow.

Model calculations were observed to be sensitive to forebay elevation changes. This affect is experienced throughout the section of the Main Interceptor Sewer in the City of Newark. Maximum hydraulic grade elevations are also affected in the South Side Interceptor Sewer, but to a lesser extent.

## 5.2 CALIBRATION AND VERIFICATION PERIOD SELECTION

Dry and wet weather calibrations are conducted to assure that two forcing functions of the computer model are defined correctly, that being sanitary flows and runoff flows, as well as correctly defining how the model reacts to these forcing functions. Dry weather calibrations assure that sanitary flows entering the interceptor sewer system are appropriately assigned and allocated. Wet weather calibrations assure that the calculation of precipitation-induced runoff from catchment areas throughout the drainage area represented by the model are performed correctly, and that the model correctly performs hydraulic calculations under free flowing and surcharged conditions. Therefore, it is critically important that appropriate conditions are selected for dry and wet weather calibrations.

Calibration and verification of the PVSC interceptor sewer model began with a review of the precipitation monitoring program and its data availability, which was previously discussed in Section 3. Rainfall data from the six temporary precipitation monitoring devices installed by Hatch Mott MacDonald, and covering the period from September 1997 through December 2001, was reviewed to select several periods to be used in the calibration and verification effort. Since gaps existed in the period of record, the data was first reviewed to identify dry and wet weather periods for which sufficient data on interceptor sewer system flow and hydraulic head was available. During the 1997-1999 field investigations, the focus was on characterizing in-system flows from regulators that were diverted into the Main Interceptor Sewer. The monitoring program from 1997-1999 provided sufficient data such that the calibration process could simulate two dry weather and three wet weather periods while the verification process could simulate two dry weather and one wet weather period, to the satisfaction of a selection rationale.

A particular rationale was applied in selecting simulation periods to represent two dry weather flow periods reflecting both relatively wet and relatively dry antecedent periods and three wet weather flow periods with different rainfall patterns. Dry weather calibration periods were sought to simulate at least a full day or more in order to reproduce typical diurnal sanitary flow patterns observed over a 24-hour period. Wet weather calibration periods were sought to include a dry antecedent period of about 24 hours such that residual effects of a previous rainfall would not complicate the analysis. Wet weather calibration periods also required sufficient data that extended for at least a full day after the end of a rainfall in order to simulate the Interceptor Sewer System's response and return to dry weather flow following a rainfall event. The rationale in selecting verification periods was the same as the calibration selection rationale.

However, the overflow characterization performed during 1999-2001 period did not involve temporary in-system monitoring and permanent meter data were also very limited. Both 1997-1999 data and 1999-2001 data were used in the calibration and verification of the interceptor sewer and regulator overflow modeling. As discussed in Section 3.3, three overflow events in the towns of Kearny, Harrison and East Newark and three events in the City of Paterson were monitored during the 1999-2001 period. Therefore, a total of ten (10) wet weather events were available for calibration and verification of the model with different amounts of data available for the Interceptor Sewer System and outfalls in different parts of the PVSC service area.

A number of sewer maintenance and improvement projects were undertaken by PVSC prior to 1999, such as slip-lining of sewer segments to enhance conveyance capacity and minimize leaks. Therefore, confirmation of conveyance characteristics in the upgraded system was undertaken by selecting four additional dry weather events for model calibration and verification from the 1999-2001

period. In total, four dry weather flow events from 1997-1999 and four events from 1999-2001 were used for dry weather flow calibration and verification.

Two distinct hydraulic models were constructed, one model simulating system upgrades so that it can be used for characterizing flow conditions in the 1999-2001 period, and a second model for characterizing system conditions that existed in the 1997-1998 period. The following sections describe the specific dry and wet weather events selected for calibration and verification of the PVSC Interceptor Sewer System model.

## 5.3 DRY WEATHER CALIBRATIONS

Four dry weather periods were identified from the monitoring record that satisfactorily fulfilled the requirements of the previously described selection rationale. Sufficient precipitation (to confirm that there was no rainfall) and hydraulic data were available for November 17-18, 1997 and December 19-20, 1997 events in the 1997-1998 period, and for April 28, 1999 and June 2, 1999 in the 1999-2001 period such that these four periods were used to calibrate the interceptor sewer model for dry weather conditions. Section 4.3 described sanitary flow conditions and methodologies for selecting baseline sanitary flows and diurnal characteristics. This effort primarily focuses on using the Extran block of SWMM to achieve the desired calibration objectives. Model parameters such as pipe roughness, length and slope, and regulator characteristics such as sanitary flow were adjusted during the dry weather calibration process, which is described here.

One of the calibration events is described in detail showing the comparisons of modeled and monitored flows and water levels. Figures for other dry weather events are presented in Appendix A for brevity.

November 17, 1997 Event: This calibration period is preceded by a full day of dry weather on November 16, 1997 that was preceded by scattered traces of rain on November 14th. All metered flow and hydraulic elevation data, from permanent and temporary meters, were available for this period except for hydraulic elevation data at the Hamilton Avenue meter. The total daily mean flow measured for this dry period was 258 MGD, which is fairly representative of the November monthly mean shown in Table 4-2 of 263 MGD but well above the monthly minimum mean and daily flow for November. When compared to the overall average of 268 MGD this condition is in the lower range of flows but well within an acceptable range for the overall monthly mean and daily flows.

The base flow used in this calibration is the actual mean flow for November 17, 1997 of 258 MGD. An initial selection of daily mean sanitary flows was guided by data sources discussed

previously in Section 4.3.1. Sanitary flows were then adjusted to reproduce flow and hydraulic elevation data. The calibration process began by focusing on the upstream section of the Main Interceptor Sewer in Paterson using the Montgomery Street hydraulic elevation meter and the Second Avenue flow meter as calibration measures. The analysis then continued downstream by analyzing cumulative flow and hydraulic elevation meters moving downstream along the Main Interceptor Sewer. Branch flows from Kearny/Harrison, Union Outlet, Jabez Street, and the South Side Interceptor were calibrated using flow data collected from branch flow meters.

The eighteen panels in Figures 5-1A through 5-1C present temporal comparisons of model computations (solid line) to hourly averaged measured flow and hydraulic elevation data (solid circle) at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers, and at the WPCF. As discussed earlier in this section, hydraulic elevation data at the Hamilton Avenue meter in Clifton (Figure 5-1A, panel D) was unavailable for this period. It should also be noted that the data presented in Figure 5-1C, panel C (Main Interceptor Sewer downstream of Jabez Street) and Figure 5-1C, panel E (Main Interceptor Sewer to WPCF) was actual data collected at these locations rather than calculated from upstream cumulative interceptor sewer and branch flow meters. It may be noted that the model overestimates water surface elevation at the Passaic hydraulic elevation meter (Fig 5-1B, panel A) despite the good agreement with the flow data at the upstream (Fig 5-1A, panel F) and downstream (Figure 5-1B, panel B) meters.

Appendix A includes Figures A-1A to A-1C for the December 19, 1997 event, Figures A-2A to A-2C for the April 28, 1999 event and Figures A-3A to A-3C for the June 2, 1999 event. The model computations compare favorably with the observed data for all four dry weather calibration events.

## 5.4 WET WEATHER CALIBRATIONS

Three wet weather periods were identified from the monitoring record that satisfactorily fulfilled the requirements of the selection rationale previously described in Section 5.2. Sufficient precipitation and hydraulic data were available for November 1, 1997, December 10, 1997, and February 11-12, 1998 such that these three periods were used to calibrate the interceptor sewer model for wet weather conditions. Similarly, three events from the 1999-2001 period were chosen such that some events included overflows observed in the City of Paterson and the rest included overflows from the Towns of Kearny, Harrison and East Newark. These events include: April 9, 1999, November 9, 2000 and March 21, 2001. Wet weather calibration primarily focuses on calibrating the Runoff block of SWMM on top of the Transport block. Runoff parameters such as drainage area, land slope, width of overland flow, Manning's surface roughness coefficients, land infiltration, evaporation, depression storage, and percent imperviousness are calibrated for generating wet weather flow. Transport block

parameters such as pipe roughness, lengths and slope, and regulator characteristics such as weir heights were also adjusted during the calibration process since the model is performing calculations under a different set of hydraulic conditions.

Correct and appropriate application of precipitation data is required for performing successful wet weather calibrations. The precipitation monitoring network described in Section 3.1 provided significant spatial coverage of the PVSC service area. Runoff calculations in SWMM can be forced by either a single hyetograph applied to all subcatchment areas or by multiple hyetographs applied to particular subcatchment areas. The PVSC service area is approximately 150 square miles extending from Newark Bay to the upper regions of Passaic River Basin adjacent to Great Falls in Paterson. The distance between the most southern and northern ends of the service area (Bayonne to Hawthorne, respectively) is over twenty miles. Combined sewer areas affected by wet weather flow are separated by approximately seven miles (Newark and Paterson). Therefore multiple hyetographs were selected for representing the northern combined sewer area of Paterson and the southern areas in Newark. The Madison Fire Station precipitation monitoring device in Paterson was assigned for Paterson drainage areas, the Kearny device for Kearny, the Harrison device for Harrison and Newark areas, and the Newark International Airport (EWR) record was assigned for Jabez and South Side areas. Table 5-1 presents a summary of volumes and maximum intensities recorded at these locations for the ten (10) wet weather events chosen for calibration and verification.

The PVSC Interceptor Sewer System has ten flow regulating devices that are remotely operated from the PVSC WPCF. Flow entering the Interceptor Sewer System through these devices are restricted when flows entering the WPCF increase to its wet weather capacity. Six of these devices are located on the Main Interceptor Sewer in the City of Newark, two are on the Kearny/Newark/Harrison branch interceptor sewer, one is on the South Side Interceptor Sewer, and one is on the Main Interceptor Sewer in Paterson. The gate mechanism of all devices is open/close except the South Side Interceptor Sewer device, which acts as a throttling gate that allows portions of the flow to enter the Interceptor Sewer System. SWMM can simulate such structures by specifying forcing parameters such as flow, hydraulic elevations, time, etc. PVSC WPCF personnel did in fact operate all ten remote devices during all ten wet weather calibration and verification periods. A time function was chosen to simulate the opening and closing of gates using actual times recorded in the PVSC gate operation records. One of the wet weather calibration events is described in detail here, and the figures corresponding to the remaining five are provided in Appendix B for brevity.

Table 5-1. Summary of Precipitation for Wet Weather Calibration and Verification Events

| Events | Rain Gages | Total Rainfall (inches) | Average Intensity (in/hr) | Peak Intensity (in/hr) | Duration (hr) |
|---|---|---|---|---|---|
| Event #1 (Nov 1,1997) Calibration | Kearny Police Dept. | 1.22 | 0.081 | 0.22 | 15.00 |
| | Wallington Pumping Station | 1.56 | 0.104 | 0.32 | 15.00 |
| | Paterson Fire Dept. | 1.36 | 0.091 | 0.27 | 15.00 |
| | PVWC Reservoir | 1.21 | 0.081 | 0.20 | 15.00 |
| | Harrison Fire Dept. | 1.09 | 0.073 | 0.24 | 15.00 |
| | Bloomfield | 1.49 | 0.093 | 0.26 | 16.00 |
| | PVSC WPCF | 0.68 | 0.057 | 0.17 | 12.00 |
| | EWR* | 0.82 | 0.055 | 0.15 | 15.00 |
| Event #2 (Nov 8,1997) Verification | Kearny Police Dept. | 0.43 | 0.043 | 0.28 | 10.00 |
| | Wallington Pumping Station | 0.71 | 0.071 | 0.25 | 10.00 |
| | Paterson Fire Dept. | 0.79 | 0.079 | 0.25 | 10.00 |
| | PVWC Reservoir | 0.89 | 0.089 | 0.26 | 10.00 |
| | Harrison Fire Dept. | 0.43 | 0.043 | 0.17 | 10.00 |
| | Bloomfield | 0.36 | 0.036 | 0.11 | 10.00 |
| | PVSC WPCF | 0.48 | 0.044 | 0.20 | 11.00 |
| | EWR* | 0.50 | 0.045 | 0.14 | 11.00 |
| Event #3 (Dec 10,1997) Calibration | Kearny Police Dept. | 0.19 | 0.015 | 0.04 | 13.00 |
| | Wallington Pumping Station | 0.03 | 0.015 | 0.02 | 2.00 |
| | Paterson Fire Dept. | 0.01 | 0.010 | 0.01 | 1.00 |
| | PVWC Reservoir | 0.01 | 0.010 | 0.01 | 1.00 |
| | Harrison Fire Dept. | 0.47 | 0.026 | 0.11 | 18.00 |
| | Bloomfield | 0.03 | 0.015 | 0.02 | 2.00 |
| | PVSC WPCF | 0.62 | 0.033 | 0.11 | 19.00 |
| | EWR* | 0.58 | 0.039 | 0.10 | 15.00 |
| Event #4 (Feb 11,1998) Calibration | Kearny Police Dept. | 0.70 | 0.058 | 0.27 | 12.00 |
| | Wallington Pumping Station | 0.75 | 0.094 | 0.27 | 8.00 |
| | Paterson Fire Dept. | 0.87 | 0.079 | 0.26 | 11.00 |
| | PVWC Reservoir | 0.91 | 0.091 | 0.26 | 10.00 |
| | Harrison Fire Dept. | 0.65 | 0.130 | 0.26 | 5.00 |
| | Bloomfield | 0.74 | 0.093 | 0.25 | 8.00 |
| | PVSC WPCF | NA | NA | NA | NA |
| | EWR* | 0.77 | 0.051 | 0.28 | 15.00 |
| Event #5 (April 9,1999) Calibration | Kearny Police Dept. | 0.45 | 0.028 | 0.11 | 16.00 |
| | Wallington Pumping Station | 0.44 | 0.029 | 0.12 | 15.00 |
| | Paterson Fire Dept. | 0.44 | 0.031 | 0.13 | 14.00 |
| | PVWC Reservoir | 0.42 | 0.030 | 0.12 | 14.00 |
| | Harrison Fire Dept. | 0.42 | 0.028 | 0.10 | 15.00 |
| | EWR* | 0.45 | 0.032 | 0.08 | 14.00 |
| Event #6 (April 20, 1999) Verification | Kearny Police Dept. | 0.29 | 0.048 | 0.10 | 6.00 |
| | Wallington Pumping Station | 0.35 | 0.058 | 0.11 | 6.00 |
| | Paterson Fire Dept. | 0.30 | 0.050 | 0.12 | 6.00 |
| | PVWC Reservoir | 0.30 | 0.043 | 0.11 | 7.00 |
| | Harrison Fire Dept. | 0.27 | 0.045 | 0.10 | 6.00 |
| | EWR* | 0.25 | 0.031 | 0.06 | 8.00 |
| Event #7 (Sept 30,1999) Verification | Kearny Police Dept. | 0.60 | 0.200 | 0.29 | 3.00 |
| | Wallington Pumping Station | 0.84 | 0.210 | 0.37 | 4.00 |
| | Paterson Fire Dept. | 1.00 | 0.250 | 0.46 | 4.00 |
| | PVWC Reservoir | 1.02 | 0.255 | 0.43 | 4.00 |
| | Harrison Fire Dept. | 0.58 | 0.193 | 0.28 | 3.00 |
| | EWR* | 0.57 | 0.190 | 0.27 | 3.00 |
| Event #8 (Nov 9,2000) Calibration | Kearny Police Dept. | NA | NA | NA | NA |
| | Wallington Pumping Station | 1.76 | 0.126 | 0.38 | 14.00 |
| | Paterson Fire Dept. | 1.56 | 0.098 | 0.28 | 16.00 |
| | PVWC Reservoir | 1.36 | 0.086 | 0.31 | 15.83 |
| | Harrison Fire Dept. | NA | NA | NA | NA |
| | EWR* | 1.20 | 0.086 | 0.26 | 14.00 |
| Event #9 (March 21, 2001) Calibration | Kearny Police Dept. | 1.98 | 0.068 | 0.27 | 29.00 |
| | Wallington Pumping Station | 1.99 | 0.069 | 0.32 | 29.00 |
| | Paterson Fire Dept. | 1.97 | 0.064 | 0.38 | 31.00 |
| | PVWC Reservoir | 1.67 | 0.056 | 0.33 | 30.00 |
| | Harrison Fire Dept. | 2.09 | 0.072 | 0.24 | 29.00 |
| | EWR* | 2.10 | 0.068 | 0.37 | 31.00 |
| Event #10 (Dec 8,2001) Verification | Kearny Police Dept. | 0.75 | 0.063 | 0.13 | 12.00 |
| | Wallington Pumping Station | 0.75 | 0.050 | 0.13 | 15.00 |
| | Paterson Fire Dept. | 0.75 | 0.063 | 0.14 | 12.00 |
| | PVWC Reservoir | 0.79 | 0.053 | 0.13 | 15.00 |
| | Harrison Fire Dept. | 0.83 | 0.052 | 0.14 | 16.00 |
| | EWR* | 0.75 | 0.044 | 0.09 | 17.00 |

*Permanent Precipitation Gage

November 1, 1997 Event: A significant volume of precipitation occurred in the PVSC service area during this wet weather calibration period - November 1, 1997. Total rainfall volumes varied from a minimum of 0.68 inches at the PVSC WPCF precipitation monitoring device to a maximum of 1.56 inches recorded by the Passaic device. This event has the highest volume totals of the three calibration events chosen in the 1997-1998 period. Maximum rainfall intensities varied from 0.15 inches per hour at Newark International Airport (EWR) to 0.32 inches per hour at Passaic. Figure 5-2 presents rainfall hyetographs displaying hourly rainfall volumes for all eight monitoring devices in the PVSC service area for this event. The November 1st wet weather event was preceded by four full days of dry weather. The total daily mean flow for November 1st was recorded at 310 MGD. The preceding dry day (October 31, 1997) total and force main flows were recorded at 245 MGD and 53 MGD respectively, which is a low flow condition when compared to November monthly statistics in Table 4-2, but well within the daily range for the month. All metered flow and hydraulic elevation data, from permanent and temporary meters, was available for this period. Sanitary flow rates and allocations were initially specified using information developed for the dry weather calibrations.

A first component of this calibration effort was focused on selecting a proper estimation of the amount and rate of surface runoff generated in the Paterson drainage area. Flow and hydraulic elevation monitoring devices located in the Paterson reaches of the Main Interceptor Sewer provided data to which model-calculated flows and hydraulic elevations could be compared. Runoff parameters were adjusted to match the peak flow produced during the precipitation event. The width of the subcatchment area, which was considered as a calibration parameter for surface velocity and time of travel, was adjusted to match time of peak flows and elevations. The sanitary flow rates for separately sewered areas were calibrated during the dry weather calibration but were adjusted to account for I/I during the wet weather event. For some separately sewered areas, peaking factors were added to generate additional I/I component during wet weather events.

Figures 5-3A through 5-3C present temporal comparisons of model computations to hourly averaged flow and hydraulic elevation data at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers, and at the WPCF. Shown in Figures 5-3D and 5-3E are overflows estimated at the outfalls in the City of Paterson and the Towns of Kearny, Harrison and East Newark. Some discrepancies between calculations and observations can be seen at the Second River Venturi Meter (Figure 5-3B, panel B) where peak and minimum flows are, respectively, under and overestimated by the model. However, calibrations upstream and downstream of this location are reasonable. Peak flows are also underestimated for the Jabez Street branch interceptor sewer (Figure 5-3C, panel B) but downstream in the Main Interceptor Sewer the model reproduces observations more accurately (Figure 5-3C, panel C). The overflows in the City of Paterson (006 - Montgomery Street, 029 - Loop Road, 025 - 10th Avenue and 33rd Street, 030 - 19th Avenue and 027 - Market Street) are shown in the five panels in Figure 5-3D. Similarly, the overflows at 006 - Johnston Avenue, 001 - East Newark, 007 - Ivy Street, and 007 - Washington Avenue in the Towns

of Kearny, Harrison and East Newark are shown in Figure 5-3E. As shown, observed data at the outfalls were not available for this event. The precipitation distribution and in-system/overflow comparisons for other events are provided in Appendix B: Figures B-1 and B-2A through B-2E for December 10, 1997 event, Figures B-3 and B-4A through B-4E for February 11, 1998 event, Figures B-5 and B-6A through B-6E for April 9, 1999 event, Figures B-7 and B-8A through B-8E for November 9, 2000 event, and Figures B-9 and B-10A through B-10E for the March 21, 2001 event.

Overall, the model computations compare well to the hourly averaged flow and hydraulic elevation data at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers, and at the WPCF and nine overflow locations in Paterson, Kearny, Harrison and East Newark. The model reasonably reproduced peak flow and surcharge conditions observed throughout the Interceptor Sewer System during these events.

## 5.5 MODEL VERIFICATION

The verification of a computer model relies on information developed during the calibration process and tests the validity of procedures that would be used when simulating projections. Specifically, the set of model parameters and procedures developed during the calibrations are finalized and used in verification simulations without any event-specific adjustments. Several sets of model parameters were developed in the dry and wet weather calibrations. These parameters were averaged for specifying a single set of parameters that were used for model verification. Just as in the calibration process, it is important to select verification periods that approximate scenarios that would be simulated in projections. Two dry and one wet weather verification periods were selected using the rationale discussed in Section 5.2 from the 1997-1998 period: October 13, 1997 and February 26, 1998 for dry weather verification and November 8, 1997 for wet weather verification. Similarly, two dry events- September 2, 1999 and November 1, 1999 were chosen for verification from the 1999-2001 period. The events April 20, 1999, September 30, 1999 and December 8, 2001 were chosen for wet weather verification from the 1999-2001 period in which the overflow data were available.

A procedure for the use of Interceptor Sewer Model was developed during the calibration process. Once a simulation period is selected, the monthly mean WPCF flow and Force Main flow shown in Table 4-2 are selected for the month that would be simulated. The Force Main flow is subtracted from the WPCF flow and is used to specify sanitary flows throughout the Interceptor Sewer System. These flows are allocated using percentages that were developed during the calibration process. In wet weather simulations, rainfall hyetographs are applied. The following sections describe one dry weather and two wet weather verification periods. The remainder of the dry and wet weather verification event comparisons are provided in Appendix C for brevity.

Dry Weather Verification Period - October 13, 1997

October 13, 1997 was preceded by almost two weeks of dry weather. Several metered flows and hydraulic elevation data, from permanent and temporary meters were unavailable for this period. However, sufficient data was available to spatially verify the model in general. The total daily mean flow measured for October 13th was 228 MGD, which is below the minimum October monthly mean flow of 253 MGD as shown in Table 4-2. The October 13th flow is only slightly above the daily minimum of 222 MGD. These statistics indicate that this day is not an ideal verification case but it was chosen due to the limited amount of complete data sets available that fulfilled the dry weather selection rationale. Force Main flow data for October 13th was not available either.

Sanitary flows were selected in this verification by using mean October flows provided in Table 4-2 for WPCF flow (253 MGD) and Force Main flow (53 MGD). Subtracting the Force Main flow from the WPCF flow results in 200 MGD. The 200 MGD flow was then allocated throughout the Interceptor Sewer System using percentages developed during the calibration process.

The Figures 5-4A through 5-4C present temporal comparisons of model computations to hourly averaged measured flow and hydraulic elevation data at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers, and at the WPCF. The model predictions compare favorably with observed data for this verification period.

Wet Weather Verification Period - November 8, 1997

This is a moderate precipitation event that was preceded by five full days of dry weather. Precipitation volumes recorded on November 8, 1997 varied from a minimum of 0.43 inches in Harrison to a maximum of 0.89 inches in Paterson. The duration of the precipitation event was nine hours that had two distinct peak rainfall periods separated by a couple of hours with only trace rainfall. The volumes, intensities and duration of the event are slightly above the averages shown on Table 3-1 for the monitoring locations during 1997-1998, but well below the maximums. Figure 5-5 provides rainfall hyetographs for the eight precipitation monitoring locations in the PVSC service area. The total daily mean flow for November 8th was recorded at 292 MGD. On the preceding dry day (November 7th) total flow and force main flow were recorded at 246 MGD and 56 MGD respectively. The total flow is lower than monthly mean flows for November (Table 4-2) and just above the minimum monthly mean of 244 MGD.

Sanitary flows were selected by using mean November flows provided in Table 4-2 for WPCF flow (263 MGD) and Force Main flow (57 MGD). Subtracting the Force Main flow from the WPCF flow results in 206 MGD. The 206 MGD flow was then allocated throughout the Interceptor Sewer System using percentages developed during the calibration process.

Figures 5-6A through 5-6C present temporal comparisons of model computations to hourly-averaged measured flow and hydraulic elevation data at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers, and at the WPCF. The overall inflow to the WPCF is predicted very well, and the in-system elevations and flows predicted by the model match reasonably well with the observed data. Figures 5-6D and 5-6E show the predicted overflow hydrographs at the nine locations within Kearny, Harrison, East Newark and Paterson.

Wet Weather Verification Period - September 30, 1999

This is a moderate rain event that was preceded by four days of dry weather. Precipitation volumes during this event ranged from a minimum of 0.57 inches in EWR to a maximum of 1.02 inches in PVWC Reservoir. The duration of the event was three to four hours with a single peak intensity of 0.27 inches per hour at Newark International Airport. The volume, peak intensity of the event are above the averages shown on Table 3-1 for the monitoring locations during 1997-1998, but well below the maximums. On the other hand, the duration of the event is shorter than the averages indicating that this is one of the intense precipitation events. Figure 5-7 shows rainfall distributions for the eight precipitation monitoring locations in the PVSC service area. The total daily mean flow for this event was recorded at 277 MGD. On the preceding dry day (September 29, 1999) total flow and force main flow were recorded at 222 MGD and 55 MGD respectively. The total flow is lower than monthly mean flow for September (referring to Table 4-2) and is well above the minimum monthly mean of 211 MGD.

Sanitary flows were selected by using mean September flows provided in Table 4-2 for WPCF flow (250 MGD) and Force Main flow (55 MGD). Subtracting the Force Main flow from the WPCF flow results in 195 MGD. This 195 MGD was then distributed throughout the Interceptor Sewer System using percentages developed during the calibration process.

Figures 5-8A through 5-8E present temporal comparisons of model computations to hourly-averaged measured flow and hydraulic elevation data at eighteen locations along the Main Interceptor Sewer, South Side Interceptor Sewer, branch interceptor sewers and at the WPCF, and also at nine overflow locations in Kearny, Harrison, East Newark and Paterson.

The comparison between observed and modeled flows and hydraulic elevations for other verification events are summarized in Appendix C for brevity and a summary of these figures is listed below:

- Figures C-1A to C-1C - Dry weather verification event on February 26, 1999
- Figures C-2A to C-2C - Dry weather verification event on September 2, 1999
- Figures C-3A to C-3C - Dry weather verification event on November 1, 1999

- Figures C-4 and C-5A to C-5E - Precipitation distribution in eight gages and wet weather verification event comparisons for the April 20, 1999 event, and
- Figure C-6 and C-7A to C-7E - Precipitation distribution in eight gages and wet weather verification event comparisons for the December 8, 2001 event.

Based on the verification events in the 1997-2001 period, the modeled flows and hydraulic elevations match very favorably with observed data.

## 5.6 MODEL ASSESSMENT

Overall, the model performance was assessed based on the ten wet weather flow events and eight dry weather flow events. Calibration of hydrologic and hydraulic model parameters based on a single wet or dry weather event can be accomplished to achieve best correlation between monitored and modeled data. However, the use of a range of wet (representing moderate to high precipitation conditions) and dry weather events enhance the robustness of the model, so that it can be used for characterizing system performance under existing as well as any future/design conditions such as a 5-year storm event. Therefore, on an event basis, there can be significant difference between monitored and modeled values, e.g., flow from Union Street branch interceptor sewer during November 1, 1997 event. Potential reasons include the use of approximate peaking factors to represent I/I and calibration of the distribution of dry weather flows from individual drainage areas in the model instead of using actual monitored flows. For assessing system flow and solids transport capacity under annual peak or extreme dry weather conditions, the calibrated dry weather flow distribution will allow apportioning of total flow to individual regulator drainage areas. Keeping these model robustness issues in perspective, the calibration and verification methodology focused on overall and system-wide match between monitored and modeled flows and water level data.

Comparisons of flow captured at the treatment plant and the overflows, as applicable, at nine outfall locations are summarized in Table 5-2 and 5-3 during all the dry and wet weather events. Based on literature and previous studies conducted by HydroQual, the general rule of thumb is to minimize the difference between monitored and modeled volumes to less than 10%. As can be seen in Table 5-2, these differences are mostly less than 10% for all events and at all locations.

Similarly, the general rule for overflows is to match the duration and peaking characteristics in the observed data. The agreement between monitored and modeled values in general is very satisfactory recognizing the variability in monitored data as well as the inherent variability in the model's capability in representing the actual hydrologic processes that govern runoff generation and conveyance within the collection system.

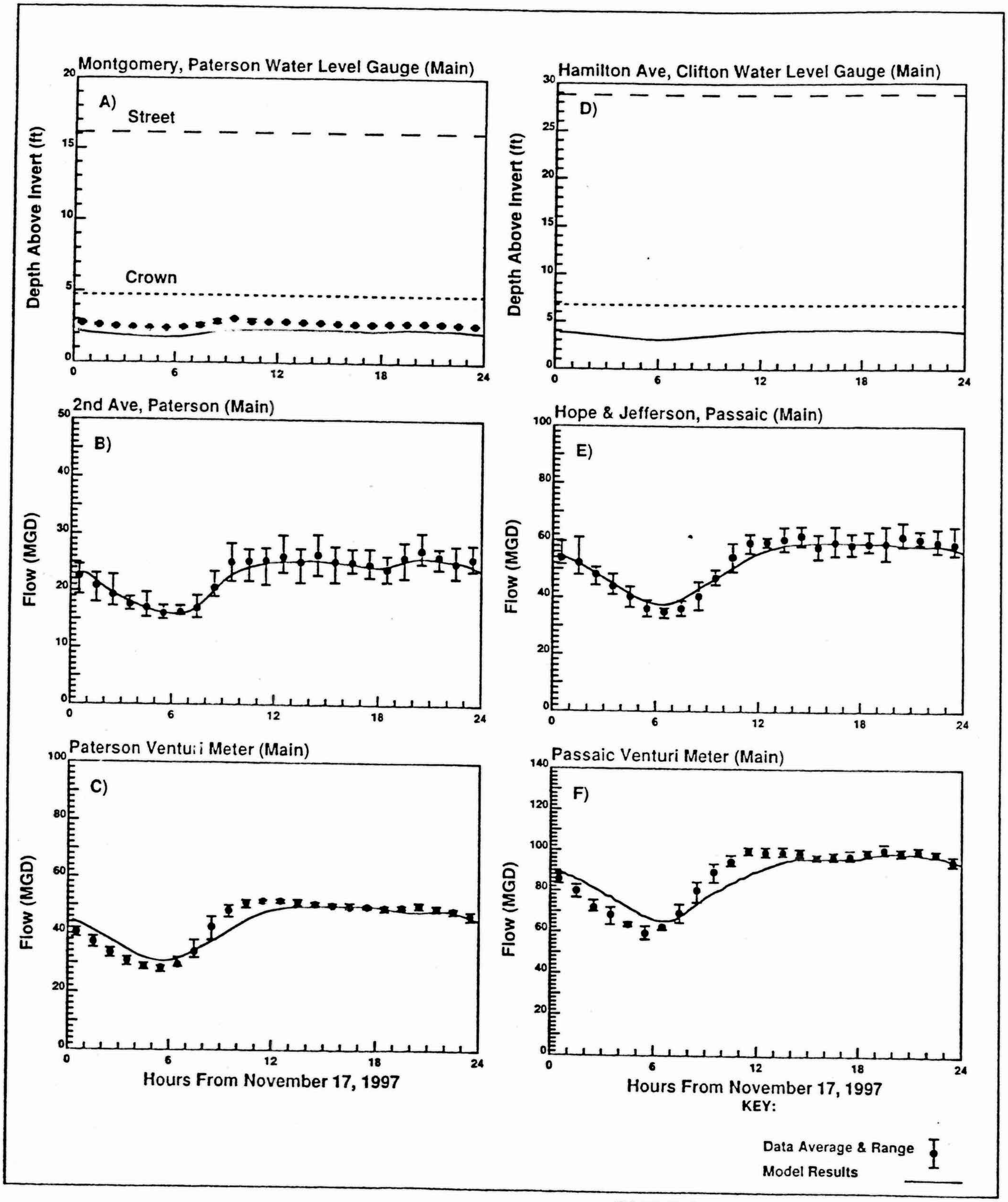
**Table 5-2: Comparison of Modeled and Monitored Flow Volumes**

| Event | Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Paterson Venturi | | | Passaic Venturi | | | Raymond Plaza | | | WPCF | | |
| | Volume Modeled (MG) | Volume Monitored (MG) | Percent Difference (%) | Volume Modeled (MG) | Volume Monitored (MG) | Percent Difference (%) | Volume Modeled (MG) | Volume Monitored (MG) | Percent Difference (%) | Volume Modeled (MG) | Volume Monitored (MG) | Percent Difference (%) |
| Dry Weather Events | | | | | | | | | | | | |
| 10/13/97 | N/A | N/A | N/A | N/A | N/A | N/A | 155.2 | 165.3 | -6.1 | 187.5 | 204.2 | -8.2 |
| 11/17/97 | 43.44 | 43.75 | -0.7 | 86.81 | 87.67 | -1.0 | 171.9 | 178.8 | -3.9 | 208.3 | 213.9 | -2.6 |
| 12/19/97 | N/A | N/A | N/A | N/A | N/A | N/A | 181.3 | 182.3 | -0.6 | 219.8 | 220.1 | -0.2 |
| 02/26/98 | N/A | N/A | N/A | N/A | N/A | N/A | 231.3 | 245.1 | -5.7 | 277.1 | 291.0 | -4.8 |
| 04/28/99 | 43.44 | 42.31 | 2.7 | 86.98 | 88.19 | -1.4 | N/A | N/A | N/A | 207.3 | 210.8 | -1.6 |
| 06/02/99 | 47.19 | 47.22 | -0.1 | 95.73 | 96.88 | -1.2 | N/A | N/A | N/A | 212.5 | 211.8 | 0.3 |
| 09/02/99 | N/A | N/A | N/A | 90.31 | 89.93 | 0.4 | N/A | N/A | N/A | 216.7 | 217.0 | -0.2 |
| 11/01/99 | N/A | N/A | N/A | 90.31 | 93.33 | -3.2 | N/A | N/A | N/A | 216.7 | 217.7 | -0.5 |
| Wet Weather Events | | | | | | | | | | | | |
| 11/01/97 | 59.58 | 51.91 | 14.8 | 116.67 | 117.71 | -0.9 | 184.4 | 172.9 | 6.6 | 266.7 | 245.1 | 8.8 |
| 11/08/97 | 55.10 | 50.35 | 9.4 | 100.31 | 102.78 | -2.4 | 171.9 | 175.7 | -2.2 | 250.0 | 239.6 | 4.3 |
| 12/10/97 | 41.67 | 48.44 | -14.0 | 86.04 | 90.97 | -5.4 | 178.1 | 188.9 | -5.7 | 242.7 | 248.6 | -2.4 |

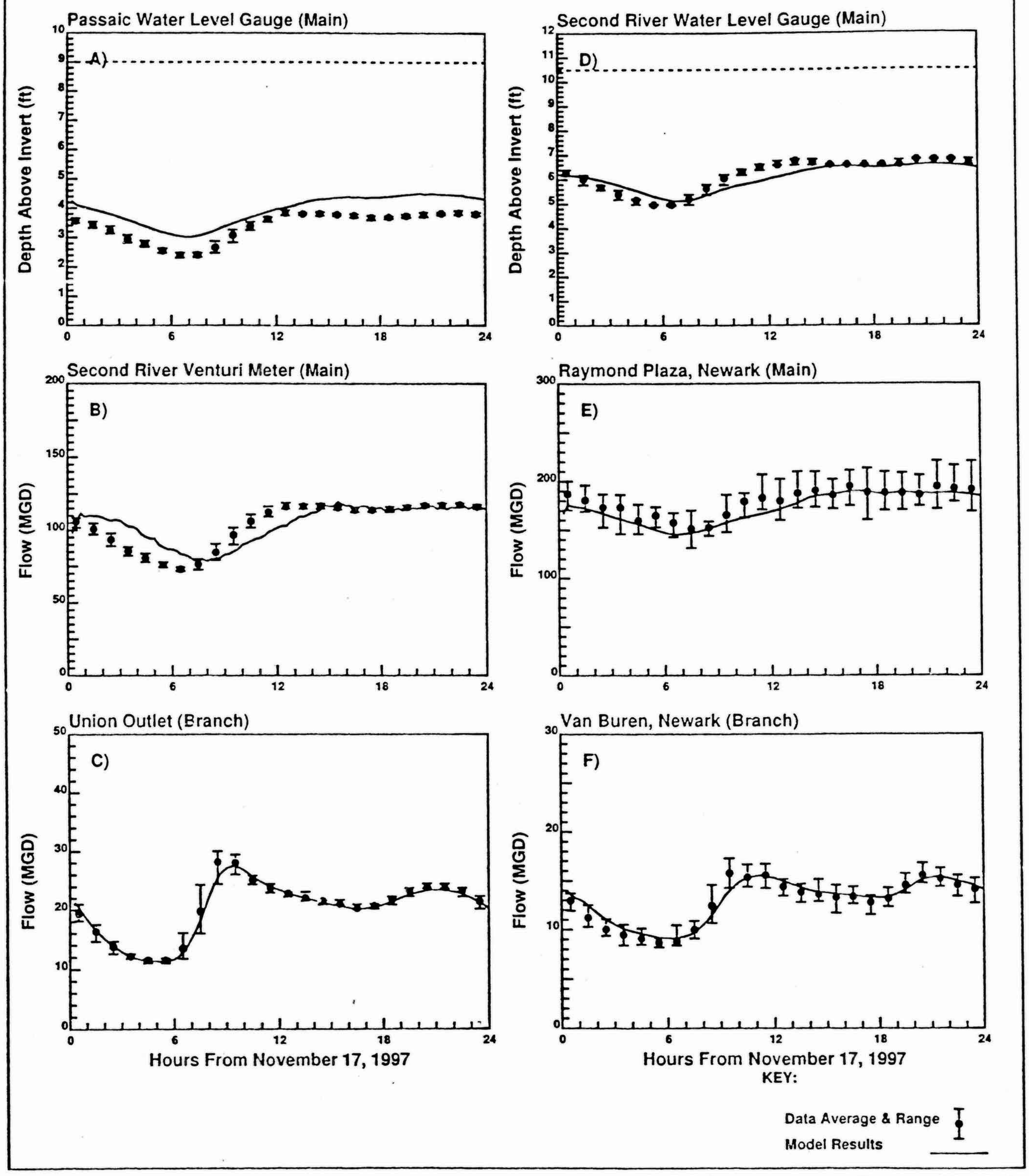
**Table 5-3: Comparison of Modeled and Monitored Overflow Volumes**

| Location | Events | | | | | |
|---|---|---|---|---|---|---|
| | Event 1 | | Event 2 | | Event 3 | |
| | Volume Modeled (MG) | Volume Monitored (MG) | Volume Modeled (MG) | Volume Monitored (MG) | Volume Modeled (MG) | Volume Monitored (MG) |
| Paterson | | | | | | |
| P-006 -- Montgomery Street | 3.85 | 1.68 | 2.40 | 19.17 | 0.97 | 1.32 |
| P-025 -- 10th Avenue & 33rd Street | 1.65 | 0.95 | 0.00 | 11.11 | 0.32 | 0.72 |
| P-027 -- Market Street | 12.71 | 9.83 | 11.04 | 8.47 | 6.51 | 2.28 |
| P-029 -- Loop Road | 2.15 | 2.45 | 3.23 | 11.39 | 0.24 | 1.13 |
| P-030 -- 19th Avenue | 1.59 | 0.91 | 2.77 | 5.21 | 0.15 | 0.18 |
| Kearny/Harrison/East Newark | | | | | | |
| K-006 -- Johnston Avenue | 0.54 | 0.25 | 0.00 | 0.37 | 1.52 | 0.50 |
| K-007 -- Ivy Street | 1.03 | 0.66 | 0.80 | 0.36 | 2.90 | 2.56 |
| E-001 -- Central Avenue | 0.00 | 0.02 | 0.00 | 0.01 | 0.25 | 0.04 |
| H-007 -- Worthington Avenue | 0.35 | 0.66 | 0.35 | 0.52 | 0.85 | 2.26 |

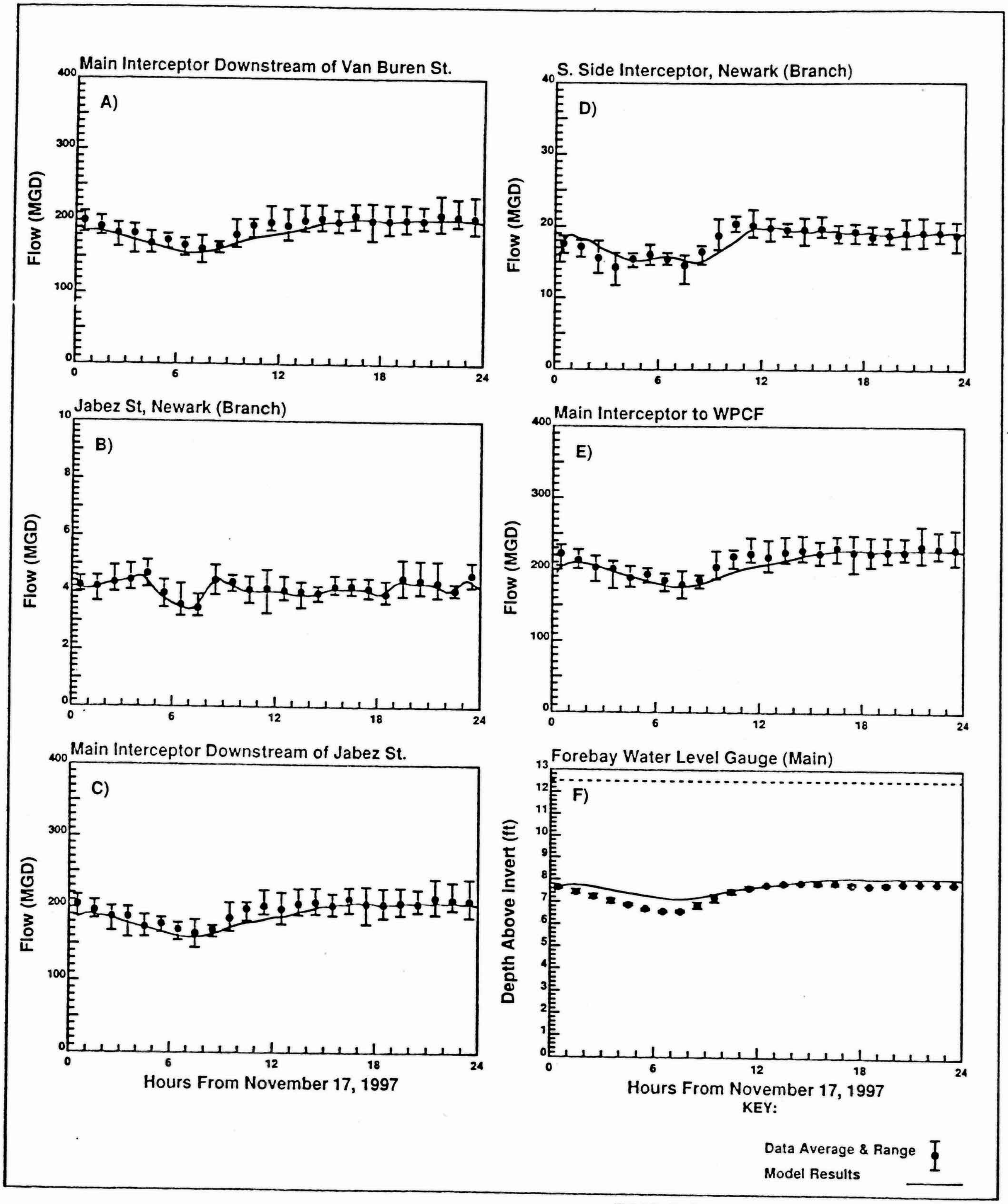
Note: For Paterson, Event 1, 2, and 3 are 11/09/00, 03/21/01 and 12/08/01 respectively.
For Kearny/Harrison/East Newark, Event 1, 2, and 3 are 04/09/99, 04/20/99 and 09/30/99 respectively.



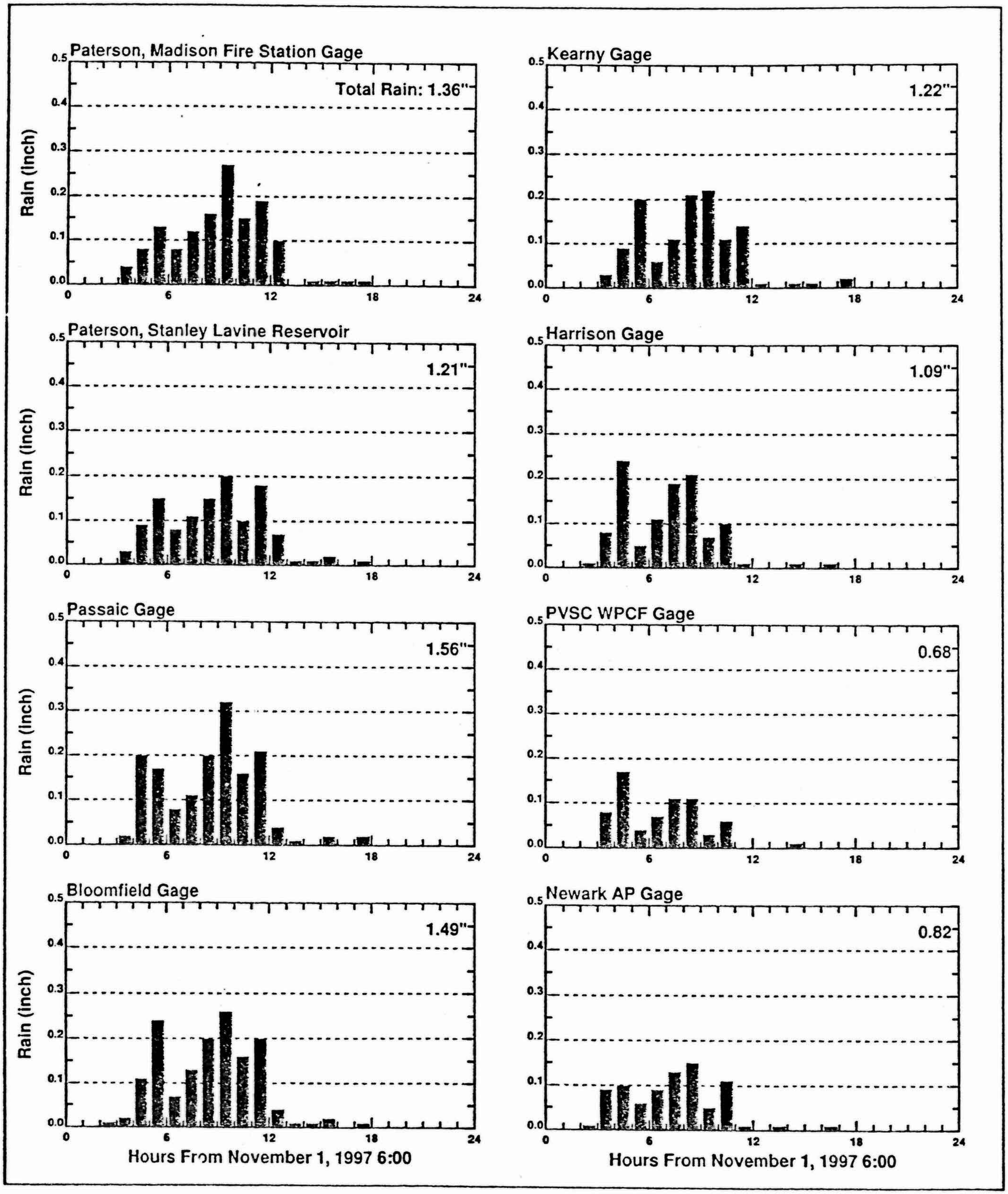

PVSC Interceptor Sewer Model
Dry Weather Calibration
November 17, 1997



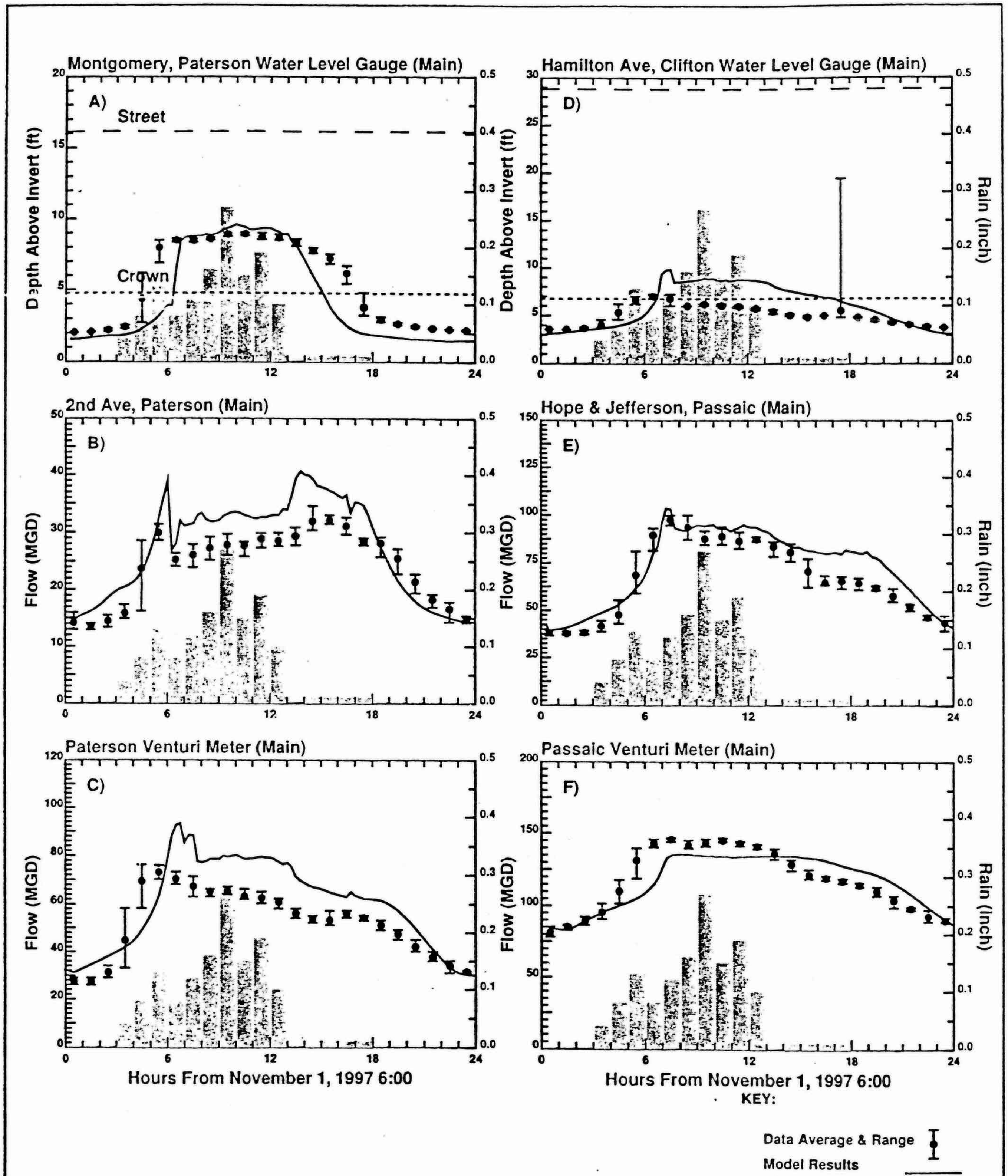

# PVSC Interceptor Sewer Model
# Dry Weather Calibration
# November 17, 1997



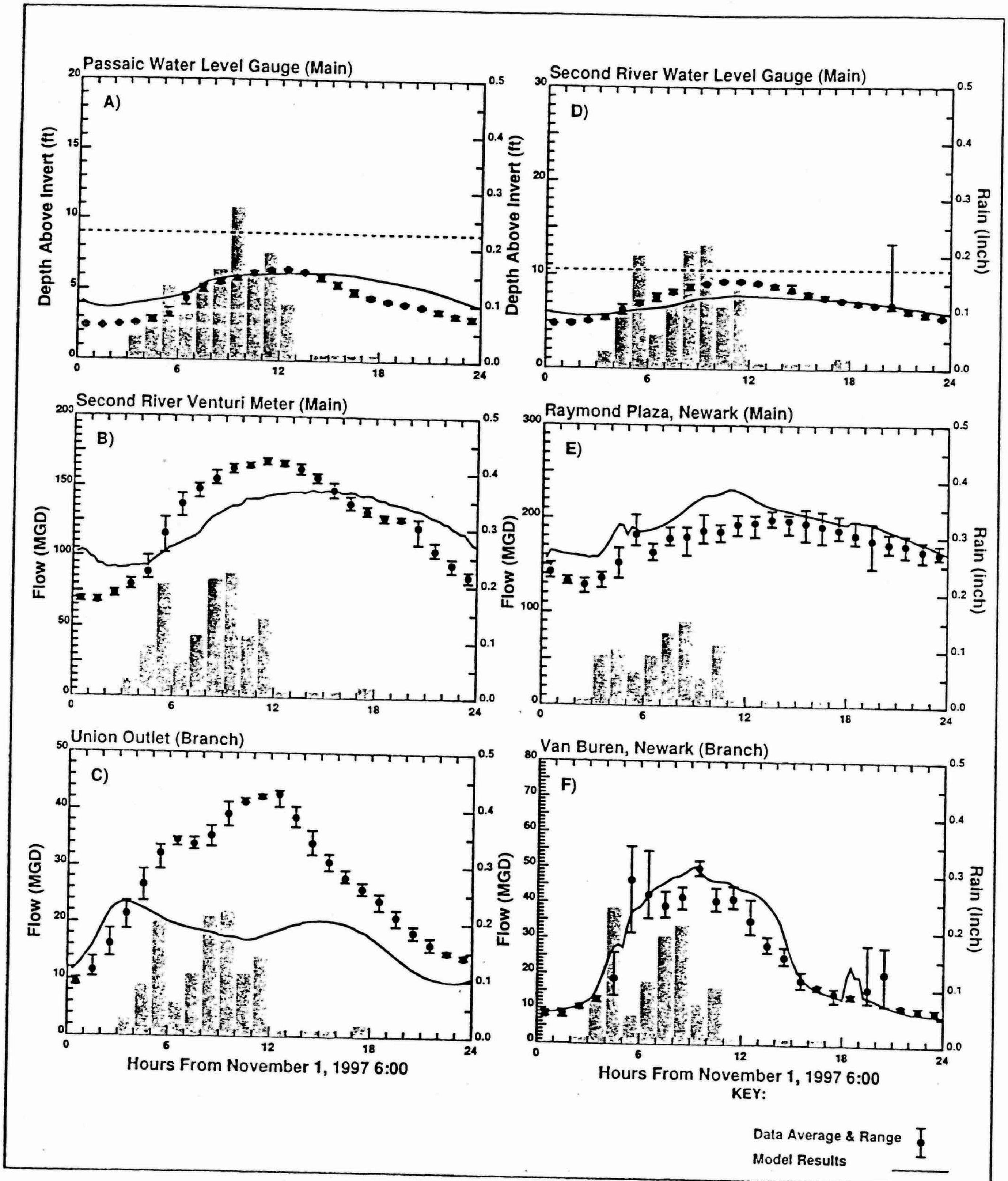

PVSC Interceptor Sewer Model
Dry Weather Calibration
November 17, 1997



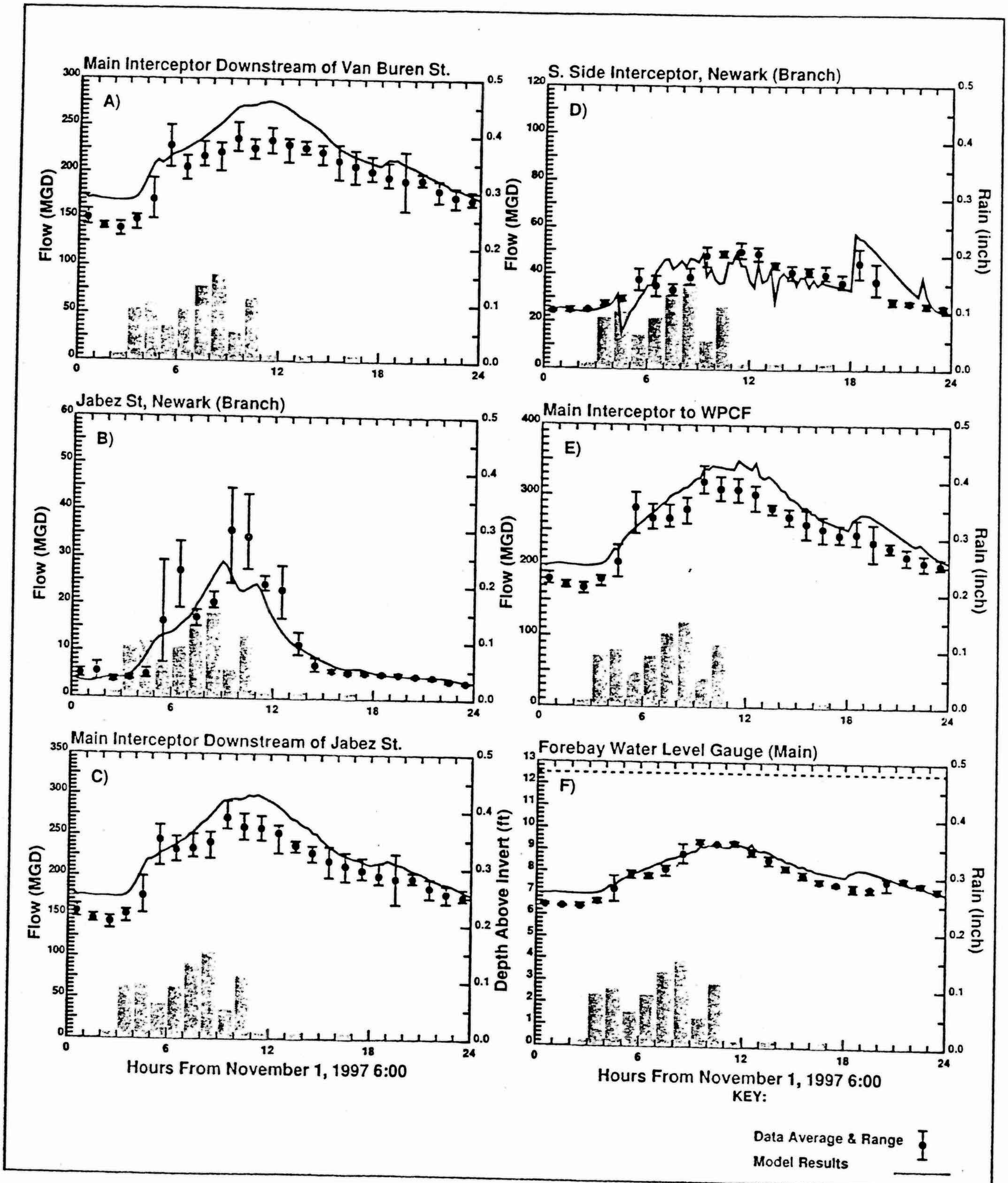

PVSC Interceptor Sewer Model
Wet Weather Calibration
November 1, 1997 Rainfall



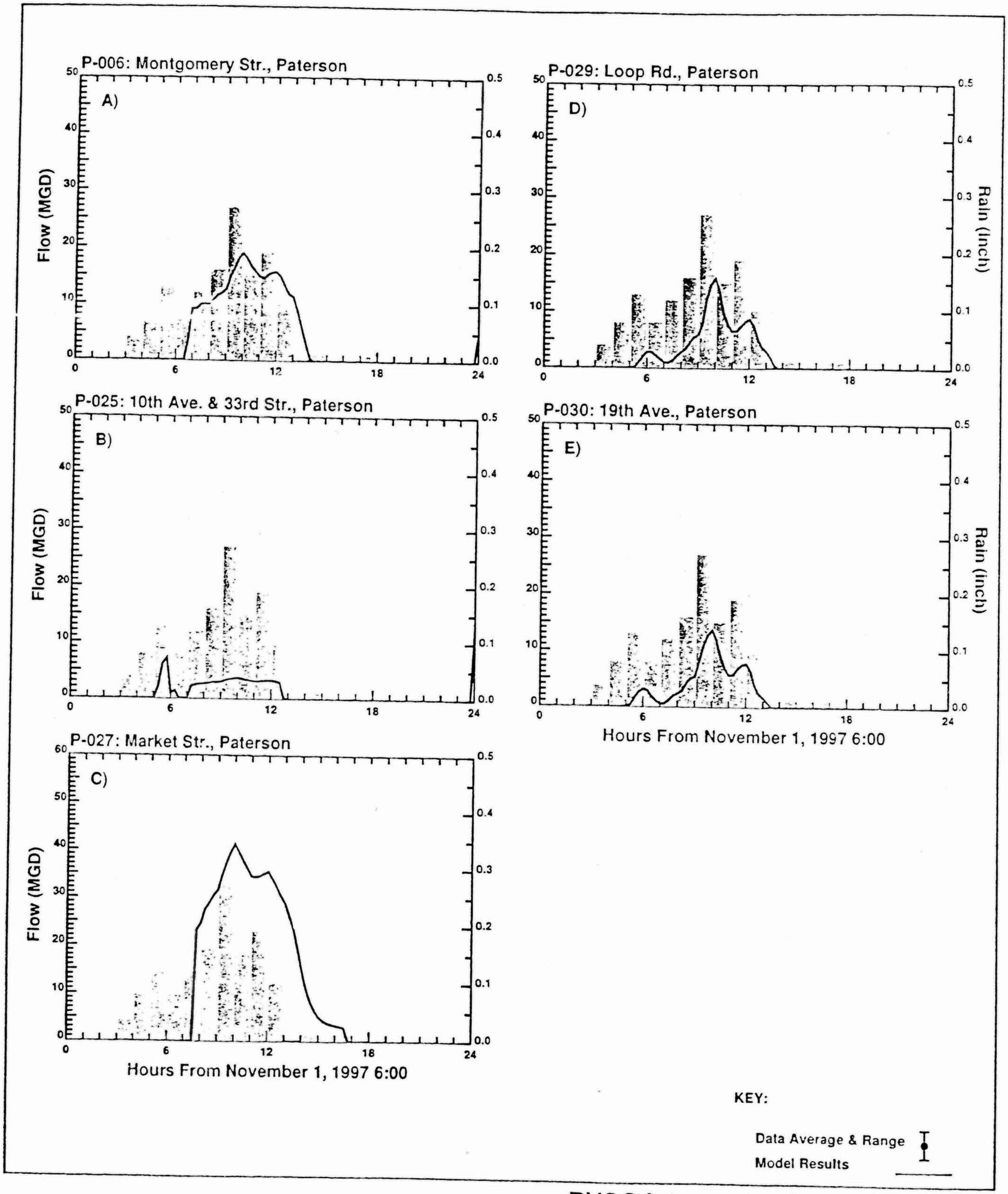

# PVSC Interceptor Sewer Model Wet Weather Calibration November 1, 1997



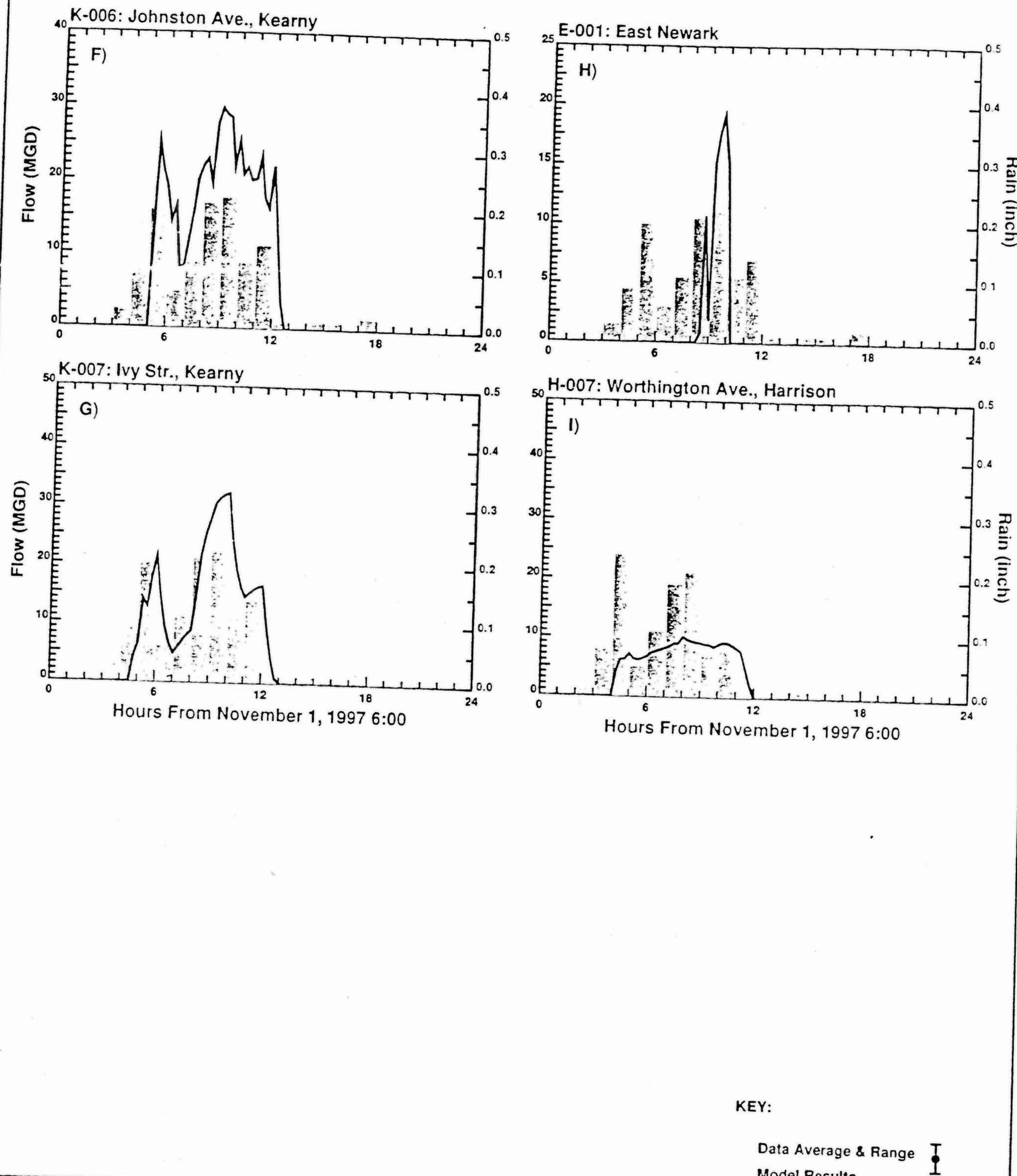

PVSC Interceptor Sewer Model
Wet Weather Calibration
November 1, 1997




# PVSC Interceptor Sewer Model
# Wet Weather Calibration
# November 1, 1997



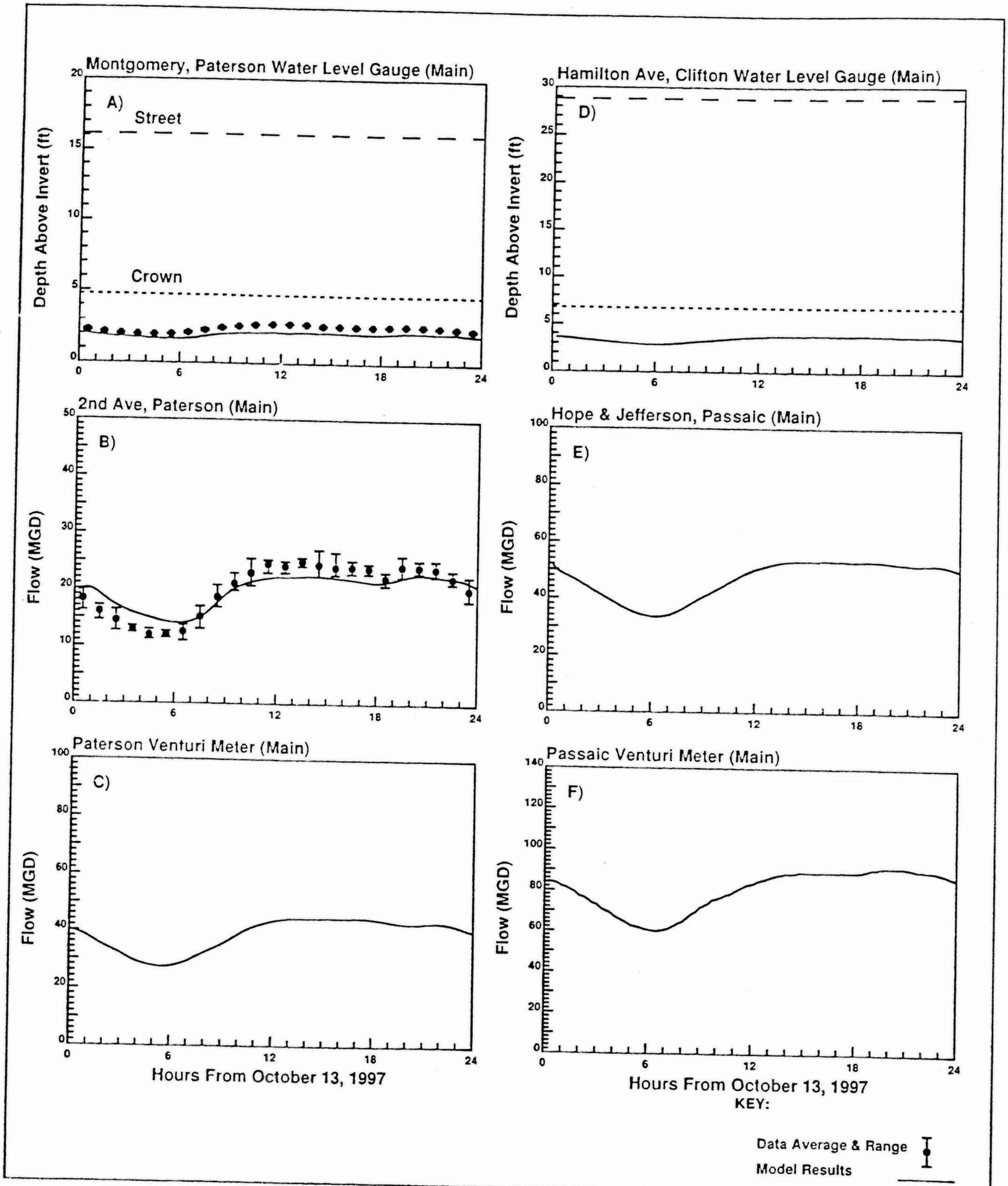

PVSC Interceptor Sewer Model
Wet Weather Calibration
November 1, 1997




PVSC Interceptor Sewer Model
Wet Weather Calibration
November 1, 1997

Passaic Valley Sewerage Commissioners

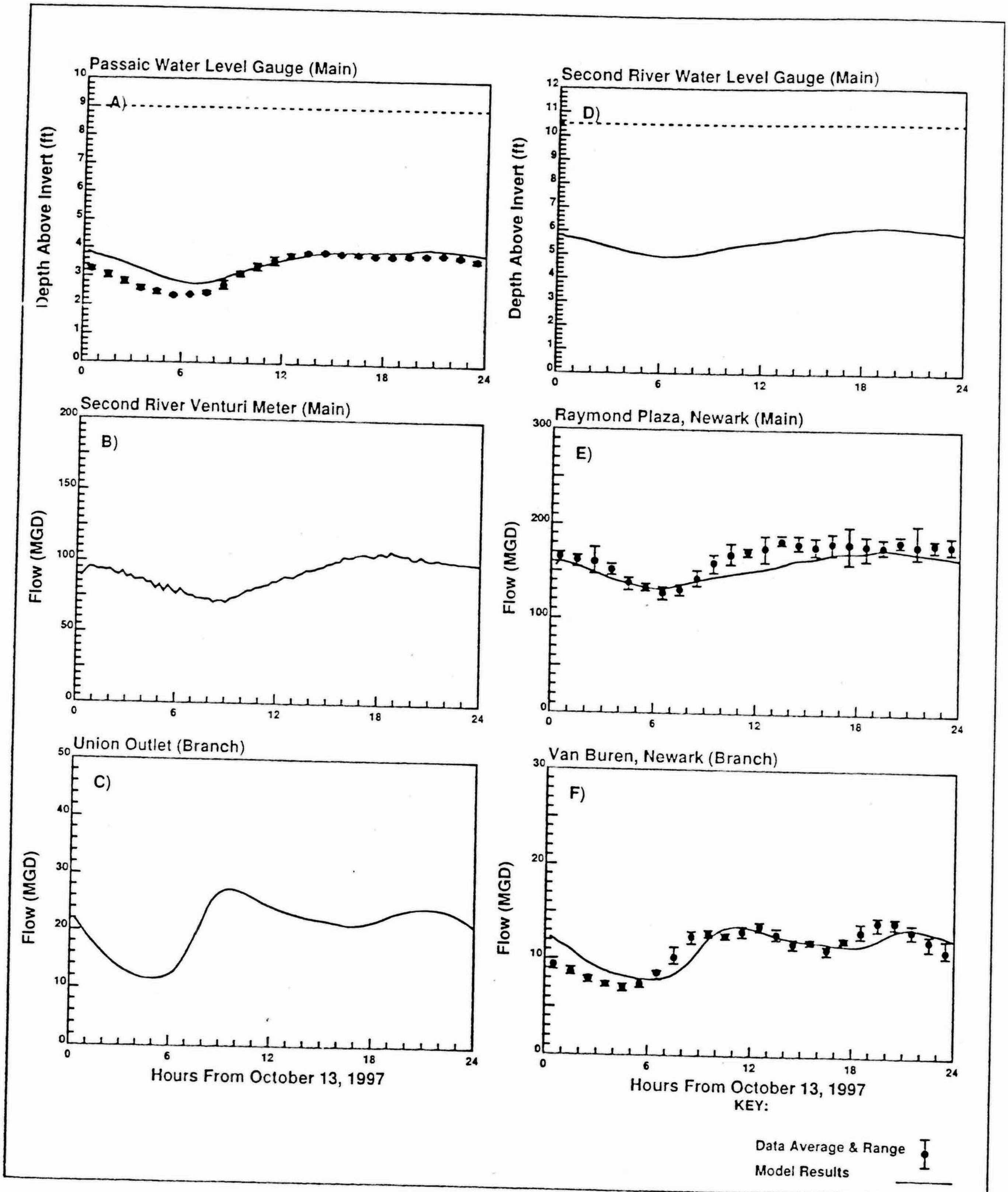
FIGURE 5-3E




PVSC Interceptor Sewer Model
Dry Weather Verification
October 13, 1997



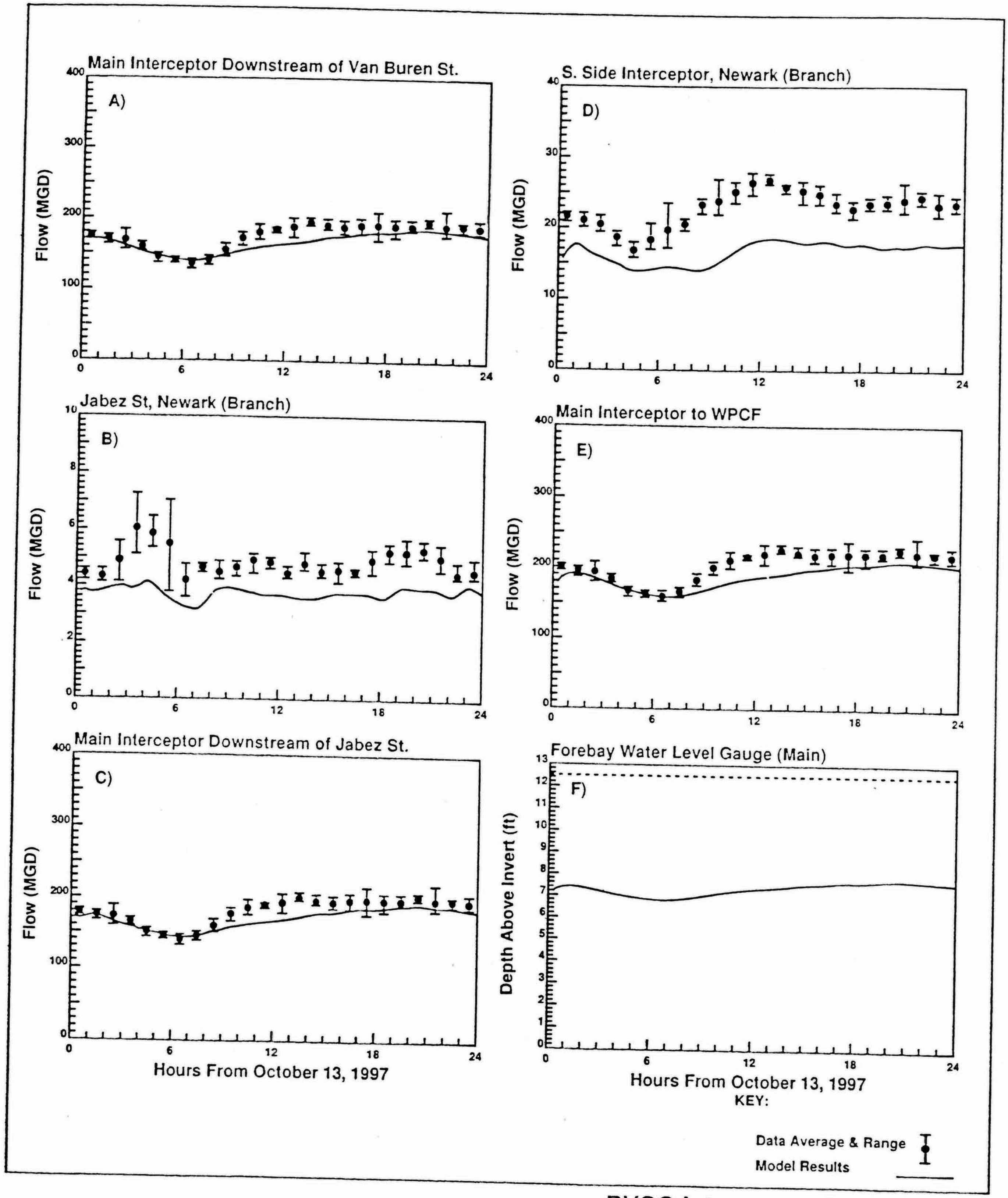
FIGURE 5-4A




# PVSC Interceptor Sewer Model Dry Weather Verification October 13, 1997

Passaic Valley Sewerage Commissioners

FIGURE 5-4B




PVSC Interceptor Sewer Model
Dry Weather Verification
October 13, 1997